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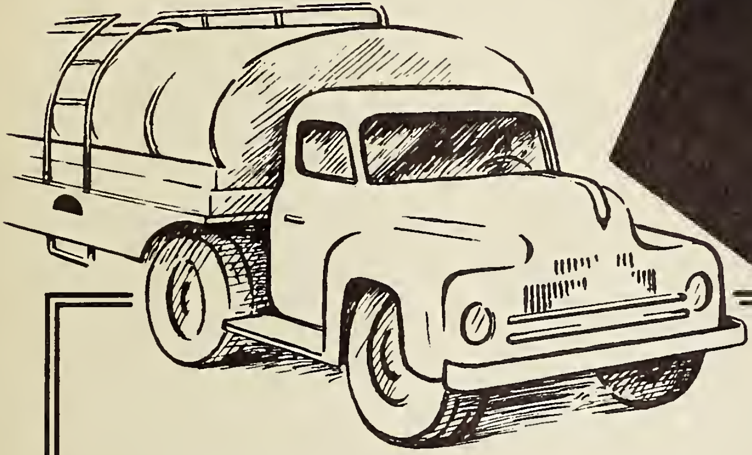
REGULATIONS ON WEIGHT OF MOTORTRUCKS

Problems Illustrated by Wisconsin's Experience in Hauling Fluid Dairy Products



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PREFACE

Ever since construction of highways began on a large scale, highway engineers have faced the problem of relating vehicle weights to a reasonable or normal rate of highway depreciation. A good deal of research has sought to establish a scientific basis for regulating truck weights.

State restrictions on the maximum weights of motor vehicles permitted to operate over the highways tend to hold down public expenditures for road construction and maintenance. Such restrictions, however, affect the direct costs incurred in transporting products. Usually when loads are reduced to a point below that which would be carried by motortrucks in the absence of restrictions, transportation costs to producers and marketing agencies tend to increase. Hence, the problem of restricting weights of vehicles becomes complex, involving as it does the measurement of damage suffered by highways as a result of traffic from vehicles of differing weights, and the balancing of the cost of such damage against both the direct effects of weight limitations on the cost of moving particular products, and the indirect effects of such costs on producers, marketing agencies, and the economy in general.

This report considers some problems of highway preservation as illustrated by Wisconsin's experience in connection with the hauling of fluid dairy products. It is concerned entirely with restrictions on the weight of trucks and their application to a part of the dairy industry's transportation system. This case study is intended to help marketing economists and others to understand better the complex nature of the problems involved in the economics of highway preservation. It is hoped that Wisconsin's experience will be useful as a guide to other States in dealing with similar problems.

This study was made under authority of the Agricultural Marketing Act of 1946 (RMA, Title II) under a research contract between the United States Department of Agriculture and the Agricultural Experiment Station of the University of Wisconsin.

Many cooperated in the project, including personnel of the Department of Agricultural Economics of the University of Wisconsin, the United States Bureau of Agricultural Economics, the Highway Advisory Committee of the Wisconsin Legislative Council, and numerous individuals and groups in the dairy and trucking industries.

Special acknowledgment is due Margaret R. Purcell, Bureau of Agricultural Economics, who made many valuable contributions to this report.

REGULATIONS ON WEIGHT OF MOTORTRUCKS

Problems Illustrated by Wisconsin's Experience in Hauling Fluid Dairy Products

By L. John Kutish [1]

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INTRODUCTION

Vehicle loads of unlimited size can cause rapid deterioration of highways. Hence all States have set maximum limits on the weights of vehicles that are permitted to use their highways. These restrictions tend to hold down public expenditures for construction and maintenance of a given system of roads.

It may not be possible to assign an accurate specific figure to the savings in public expenditures that result from a given set of restrictions on truck weight. Knowledge of relevant physical relationships is too fragmentary, and there are too many uncertain variables to permit the derivation of a complete statistic of this type. But, to be useful, it need not be complete. If a liberal weight regulation appears to allow too much of an increase in highway damage compared to a more restrictive regulation, this difference may provide sufficient basis for a legislative decision.

To an uncertain extent, additional public expenditures associated with motortrucks — that is, higher initial costs of construction of highways and higher costs of maintenance — are offset by higher licenses, fees, and taxes paid for these vehicles. If the additional public expenditures are not fully offset by the differential in these payments to the State, then the State is granting a subsidy. The amount of such a subsidy cannot be computed unless the incremental public costs and the revenues associated with the use of trucks can be learned.

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The highway-preservation aspects of trucking regulations are only one side of the coin. Truck regulations — weight restrictions and payments to the State — have an economic influence in the form of an increase in trucking costs above the level possible in the absence of the regulations. But their economic effects extend beyond an over-all increase in the total cost of a given pattern of truck transportation. In the long run, if truckers shift the added burden by raising their rates, patterns of transportation, trade, and industry may change. Economies of production organization (based, for example, on geographic specialization) may be offset by increased costs of transportation connected with the regulations. A change in the structure of industry may then result, reducing the volume of traffic or altering its pattern. These secondary economic effects are likely to be especially serious when interstate differences in truck regulations result in transportation rate differentials that cut through market areas.

An appraisal of truck regulations as trade barriers would prove to be an investigation of (1) the regulations themselves, (2) their effect on trucking costs, (3) the shifting and incidence of increases in trucking rates, (4) the resulting changes in the pattern of transportation, trade, and industry, and (5) the increase in costs to trade that might ensue. The total of the increase would indicate the magnitude of the barrier occasioned by a given set of regulations.

Again, a complete cost statistic of this kind cannot be derived to a degree of accuracy sufficient to justify the effort. But in this case, also, the information need not be complete to be useful. If the general direction of some of the secondary economic effects can be analyzed, or if the magnitude of some of the costs can be approximated — even roughly — the result may provide a basis sufficient for a legislative decision regarding a particular type of trucking regulation.

Perhaps enough has been said to indicate the complexity involved in a complete appraisal of truck-weight restrictions and of payments to the State by truckers. These restrictions help preserve the highways and to reduce public expenditures. They do impose a cost upon trade. Even though there is no exact method of ascertaining benefits and costs, some compromise, based on the best evidence available, is necessary.

This report considers some of the problems of highway preservation as they are illustrated by Wisconsin's experience in connection with the hauling of fluid dairy products. Not all types of truck regulations are considered. For example, nothing is said here concerning taxes on motortrucks and other payments to the State. Rather the report is concerned exclusively with weight restrictions on trucks and their application to part of the dairy industry's transportation system. Although the scope of the study is thus limited with regard both to type of regulation and to the segment of trade affected by the regulation, it is hoped that the report will serve as a case study, and that Wisconsin's experience will be useful as a guide to other States when they face similar problems.

The first part of the report contains a summary of some of the research and experience that form the basis of the more common types of weight limitations on highway vehicles. The second part considers the role of truck transportation in the marketing of Wisconsin fluid dairy products, the history of weight restrictions on the trucks in Wisconsin, and the effect of the law's application to trucks hauling fluid dairy products. The action concerning truck weight laws of the 1951 legislature is noted also.

SUMMARY

During the early 1920's extensive road tests were conducted in Illinois. Pavement slabs of different thicknesses were laid to form a continuous road, and trucks carrying progressively larger loads were run over it. Inadequacy of the road appeared in the form of breaks in the corners of the pavement slabs. Such breaks usually were followed by additional deterioration. When a corner break occurred, the researchers noted the thickness of that particular slab, as well as the weight applied to the pavement by the wheel that broke it.

At that time it was thought that differences in temperature between the upper and lower surfaces of a pavement slab caused it to warp upward at the corners. This part of the slab, unsupported by the grade beneath, acted as a cantilever and was particularly susceptible to damage. So, from the theory of mechanics, an equation was derived to express the relation between the depth of a simple cantilever beam and the weight it would bear at its end. This curve was fitted to the test data which related wheel loads to thickness of pavement.

In addition, the fatigue characteristics of concrete slabs were studied. It was found that concrete cantilevers could withstand an almost limitless number of applications of weight if the weight were below a certain level. Above that level, however, the beams failed after relatively few weight applications.

These two series of tests formed much of the basis for early pavement design and also for the regulations that limited the maximum loads vehicles were allowed to impose upon pavements. Historically, pavements have been built to a depth of about 8 inches, and States have limited to approximately 18,000 pounds the load allowed on an individual axle of a vehicle.

Experience has shown that the warping action caused by temperature differentials probably is not as important in deterioration of pavements as was originally supposed. A pavement that is well supported by a firm base should not act as a cantilever, hence it should not be subject to the types of stresses studied in the research mentioned above. Nevertheless, pavements have deteriorated.

Two general theories have been advanced to account for damage to pavements. The first theory holds that trucks with axle loads far above the recommended maximum are responsible. The second holds that pavements are damaged by forces of nature and that this damage can be aggravated, not only by heavy axle loads, but also by axle loads below the recommended maximum. At any rate, attention in more recent research has been focused on the subgrade support of pavements. One group of researchers believes that the collection of moisture under the slab is responsible for the distress of pavements. They recommend that, in constructing highways, a porous layer of granular material be placed under the pavement so that moisture can drain away. At present most States require this type of highway design, and in certain areas at least it has been successful.

Two recent tests conducted by the Highway Research Board of the National Research Council — the Maryland road test and the Minnesota bearing test — apparently confirm the hypothesis that performance of pavements is closely related to the condition of the grade beneath the roadway.

Another type of vehicle regulation relates to the spacing between axles. This type of regulation was originally framed in connection with the preservation of bridges. It is known that, for a given gross vehicle weight, bridge stresses vary with different vehicle lengths — that is, a short truck tends to generate greater stresses in a bridge than a longer truck of the same weight. Hence, a formula was recommended to the States which related the permissible gross weight of a vehicle to its over-all wheel base, that is, to the distance between its foremost and rearmost axles. Later the formula was revised and put into the form of a table. It was recommended at that time, however, that it apply to all combinations of axles — interior combinations as well as the over-all wheel base. In relation to axle spacings, the maximum weights prescribed by the table were recommended as safe for the type of bridge more common in the United States highway system.

One type of regulation of axle spacings and weights predated the formula referred to above. This was the limitation on the combined load that could be carried by tandem axles — that is, two axles separated by a distance of approximately 4 feet. This regulation was designed as a protection for pavement slabs because it was known that when axles are very close together the stresses they induce in a slab tend to reinforce each other. For this reason most States set a maximum on the combined weight that could be carried on tandem axles, the more common limit being 32,000 pounds. For regulatory purposes, axles closer together than 4 feet were treated as a single axle.

Recent research conducted in Maryland and Wisconsin apparently supports the hypothesis that an axle spacing as narrow as 4 feet is significantly related to pavement damage when the combined load is at least 32,000 pounds. Unfortunately, none of the research tests sheds much light on the comparative effect of axle spacings in excess of 4 feet. It seems likely that the effect of different axle spacings on pavement slabs may differ from the effect of the same axle spacings on the type of highway bridge commonly found in this country.

As a contribution to the war effort, in 1942 Wisconsin suspended the enforcement of its law restricting the weights of vehicles using the highways. This policy of nonenforcement was continued in the early postwar period. But the roads deteriorated under such unrestricted utilization, and in 1948, highway officials again began to enforce the law. Almost immediately, questions arose concerning the economic effect of a vigorous enforcement of weight restrictions on trucks, especially in connection with the trucking of fluid dairy products.

For several decades before World War II, the Wisconsin dairy industry evolved in the direction of fewer and larger plants. This consolidation was traceable ultimately to economies of large-scale production in dairy manufacturing. However, the geographic pattern of milk production in the State remained comparatively stable. Thus, to obtain the supplies of milk required to take advantage of these economies, plants used progressively more truck transportation. In addition, more trucks were used to haul milk to Chicago and other out-of-State markets.

The war accelerated almost all of the basic trends in the industry, and the use of truck facilities increased accordingly. Because the State did not enforce its weight restrictions during this period, the trend toward larger trucks went unchecked. This trend also had an economic foundation because, for a trip of a given distance, trucking costs per unit of product tend to decline if a larger quantity of product is carried.

The increase in size of motortrucks was not limited to the dairy industry. It was general among many industries, and it became the source of much concern to State officials and others interested in highway preservation.

The law regulating weights of highway vehicles which Wisconsin sought to enforce in 1948 differed from the laws of most other States. The Wisconsin law directed the State highway commission to classify the State's highways as class A or class B. Different regulations concerning the weight of vehicles applied to these two classes of roads. The class B regulations were the more restrictive. The highway commission was permitted to use its judgment regarding which roads to classify as B, the criterion being the ability of the road to carry heavy traffic. All other State highways were automatically classed as A. The classification, however, was flexible. For example, certain roads classed as B during the spring "break-up" were shifted to the A class during the remainder of the year.

It has been pointed out that most States allowed a maximum load of 18,000 pounds on an individual axle, and 32,000 pounds on tandem axles. In addition, most States had formulas or tables relating the maximum combined load that could be carried on a group of axles to the distances separating those axles. However, only a few States applied the formulas or tables to interior axle combinations.

The Wisconsin class A law allowed 19,000 pounds on an individual axle, and provided a so-called bridge formula that limited the combined load on combinations of axles, including interior combinations. This formula applied a limit of 30,000 pounds to tandem axles. The class B law allowed only 12,000 pounds on an individual axle and provided a bridge formula that permitted tandem axles only 18,400 pounds.

When enforcement of this law began in 1948, officials adopted the following policy with regard to tolerances — that is, allowance for inaccurate weighing, shifting of loads, accumulation of mud or ice on the vehicle, and the like — on class A roads: In connection with the statutory 19,000-pound limitation on an individual axle load, a tolerance of 1,000 pounds was granted. In connection with the bridge formula, a tolerance of 2,000 pounds was granted for axle combinations in which the distance from the foremost to the rearmost axles of the group under consideration was less than 12 feet. If the distance was greater than 12 feet, a tolerance of 3,000 pounds was granted.

This law made illegal the capacity operation of a great deal of truck equipment in use at the time. Even with tolerances, many trucks were unable to carry capacity payloads. This was particularly true in the dairy industry because its truck-transportation system had grown beyond these bounds during the wartime and early postwar periods of nonenforcement of regulation of truck weights.

Most of the trucks that carried milk from farm to plant, and many tank trucks that hauled fluid byproducts between dairy plants, traveled widely on class B State highways and secondary roads. These vehicles often had axle loads far above the class B maximum. In addition, many tank trucks that hauled products between Wisconsin plants, and from Wisconsin to out-of-State markets, could not comply with the class A bridge formula. Because of these things, temporary relief was granted to dairy-transportation equipment, although with the provision that the law was to be vigorously enforced beginning July 1, 1951.

In the meantime, an investigation was made by a plant representative for the purpose of estimating the increase in cost to the dairy industry that would result from rigorous enforcement of class B regulations. This investigation showed roughly that costs would increase sharply. But the savings in highway maintenance expenditures that would have resulted from vigorous enforcement were not publicly estimated. Apparently, however, the State legislature considered the cost to the industry to be high in relation to the savings in maintenance because in 1951 it repealed the classification system on State trunk highways. State administrative officials are still authorized to post the highways when conditions warrant it. This authority undoubtedly will continue to be exercised, especially during the spring when the subgrade supports for roads are weakest.

Vigorous enforcement of class A regulations would have presented the Wisconsin dairy industry with a complicated situation. With respect to the single-axle load limitation of 19,000 pounds, the industry would have suffered no real hardship on intrastate hauling. Trucks carrying fluid dairy products between plants in Wisconsin operated with axle loads up to 20,000 pounds, but they were protected by the enforcement tolerances. Some of these interplant trucks had to operate with only partial loads in order to keep their axle loads down to 20,000 pounds, but no general complaint was made on this score. Because of the lower limits permitted in other States, however, Wisconsin tank trucks carrying out-of-State shipments could not carry as much as 19,000 pounds on an axle.

The 1951 State legislature reduced the statutory single-axle load limit from 19,000 to 18,000 pounds, thus bringing it into line with the corresponding limit in most other States. The law specified, however, that a tolerance of 1,500 pounds was to be granted by enforcement officials. As a result, the effective limit was reduced only 500 pounds, from 20,000 to 19,500. It appeared that this reduction would not impose substantial additional costs on the dairy industry. It was even thought that some savings in expenditures for maintaining highways might result.

Unlike the load limitation on single axles, the class A bridge formula definitely presented a problem to the dairy industry. In connection with the Wisconsin regulation limiting the maximum lengths of vehicles to 45 feet, the bridge formula set a practical maximum gross weight of vehicles at 66,000 pounds. Illinois, which had no bridge formula, permitted gross vehicle weights up to 72,000 pounds. Under this limitation, vehicles consisting of a truck and a full trailer combination, as well as 5-axle semitrailer combinations, could operate legally in Illinois. These vehicles carried larger payloads than the 4-axle semitrailer combination which is the largest vehicle that can be operated legally in Wisconsin. Because the competitive price for milk is the delivered price, and because milk can be transported more economically in larger trucks, this placed the Illinois producers in a more favorable position in the competition for the Chicago market.

The Wisconsin bridge formula applied not only to the over-all wheel base of a vehicle, but also to interior combinations of axles. So it not only made a 4-axle semitrailer the largest permissible vehicle in the State; it also affected the distribution of weight among those axles.

A 4-axle semitrailer has a steering axle at the front of the vehicle, a drive axle at the rear of the power unit (tractor), and tandem axles at the rear of the semitrailer unit. The bridge formula created a problem with respect to the two interior groups of axles: (1) the tandem axles, and (2) the group consisting of the drive axle and the tandem axles.

The bridge formula allowed only 30,000 pounds on the tandem axles whereas the typical truck carried 31,000 pounds. Illinois, as well as most other States, allowed 32,000 pounds on tandem axles. However, the 2,000-pound bridge-formula tolerance granted by Wisconsin enforcement officials removed this problem.

For the typical 4-axle tank truck carrying milk, the formula set a combined load limit of 46,000 pounds on the group of axles that consisted of the drive and the tandem axles. Actually, the typical vehicle carried 49,500 pounds on this group of axles. So in this case the bridge-formula tolerance did not abate the problem.

Meanwhile an investigation was made regarding the actual capacities of Wisconsin bridges. These bridges are built with a safety factor of "four" — that is, they are built to carry four times the weight used in the basic design. Thus actual capacity is greater than design capacity. The bridge department of the Wisconsin State Highway Commission estimated that the rated capacity of almost all State trunk bridges well exceeded the weights allowed under the bridge formula. In fact, it was suggested that the bridge formula was viewed primarily as a device for protecting pavement slabs rather than bridges.

The 1951 legislature retained the bridge formula. However, because of the scarcity of research information regarding the effectiveness of the bridge formula as a protector of pavement slabs, the legislature provided legal tolerances sufficient to remove most of the problem of axle spacings on the 4-axle vehicles.

The question of enforcement tolerances is difficult. Some sort of tolerance is usually considered desirable. Within a given State, tolerances granted at the discretion of enforcement officials are subject to possible inconsistent application and to change without notice. Between States such tolerances vary widely. If highway laws specified tolerances, their stability, consistency of application, and uniformity among States would be encouraged. But if this were done the higher limits might tend to lose their "tolerance" character and become instead the _de facto_ legal limits.

To counter this tendency, the 1951 legislature adopted the following plan: No arrest is made if the load is less than the statutory limit plus the tolerance. If this maximum is exceeded by less than 1,000 pounds, a flat fine is imposed. If the excess weight exceeds 1,000 pounds, the fine is computed on a per pound basis, and the rate per pound increases as the overweight increases. Moreover, tolerance is lost in this connection; that is, the overweight is calculated from the statutory limit. Under this system the statutory limit retains a real meaning even though the tolerance is legally specified.

To recapitulate briefly with respect to the current situation:

In 1951 the Wisconsin legislature repealed the classification system on State truck highways, although it authorized administrative officials to post the highways when conditions warranted such action. In 1951 also the legislature reduced the statutory single-axle load limit from 19,000 to 18,000 pounds, and provided that a tolerance of 1,500 pounds was to be granted by enforcement officials. The bridge formula was retained. In the absence of research indicating the effectiveness of the bridge formula as a protector of pavement, however, the legislature provided regular tolerances sufficient to remove most of the problems of axle-spacing on 4-wheel vehicles. All major groups that were represented supported the 1951 legislation. This legislation and its accompanying regulations, however, can only be said to represent what appears to be the best adjustment to prevailing conditions in the dairy industry, in view of the limited knowledge as to the relation between vehicle weights and highway damage. Research on damage, on the effect of weight limitations and other regulations designed to preserve highways, and on transportation costs and services needs to be continued.

BASIS OF WEIGHT RESTRICTIONS ON MOTORTRUCKS

Ever since pavement construction began on a large scale, highway engineers have wrestled with the problem of relating vehicle weights to highway damage. Considerable research has been directed toward establishing a scientific basis for regulating truck weights. Several types of regulations have resulted. Two of the most important are the fixing of a limit on the load that may be carried on an individual axle of a vehicle, and on the combined load on a group of axles as related to the axle spacings.

Individual Axle Load Limitations

Early Research 2/

To provide the facts needed for the design of surfaced roads, the Illinois Division of Highways conducted a series of tests in 1922 and 1923. A special test road, which came to be known as the Bates Road, was constructed. It consisted of sections composed of various types of surfacing, including concrete. Some pavement slabs were of uniform thickness across their width, and some were of thickened-edge design.

The road was subjected to test traffic consisting of Liberty trucks equipped with solid rubber tires. These trucks were driven at speeds ranging from 12 to 15 miles an hour. During the test period, the load carried by the trucks (and consequently the pressure placed on the pavement by the wheels) was successively increased. When a critical corner break occurred in a section of pavement, the wheel load was noted in relation to the thickness of the slab. It was found that differences in temperature between the upper and lower surfaces of the slabs often caused them to warp upward at the edges. When this occurred, the warped parts of the slab were partially or wholly without base support. Clifford Older, at that time chief engineer of the Illinois Division of Highways, reasoned that unsupported corners of the slabs acted as cantilevers. Their load-carrying capacity was considered to be a measure of the capacity of the entire slab, because critical corner breaks usually were followed by additional failure of the concrete.

From the theory of mechanics, an equation was derived to express the relation between the depth of a simple cantilever beam and the weight it would bear at its extreme end. This equation was:

$$d = \sqrt{\frac{3w}{S}}$$

where d is the depth of the pavement in inches, w is the wheel load in pounds, and S is the modulus of rupture or unit-breaking stress of the concrete slab.

On the basis of this formula, a curve was fitted to the data obtained in the Bates Road test. The value for S that produced the best fit of the curve to the data was found to be 733. That is, 733 pounds per square inch was the average of the determined moduli of rupture of all the concrete sections. From

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2/ Discussion based on Part III of statement by Thomas H. MacDonald, Commissioner, Bureau of Public Roads, at hearings before Subcommittee of Senate Committee on Interstate and Foreign Commerce pursuant to Res. 50, investigating domestic land and water transportation. 81st Cong., 2d sess., 1950.

this it was concluded that the equation $d = \sqrt{\frac{3W}{733}}$ was a reasonable expression of the relation between the thickness of a concrete slab and the wheel load that would break it at its corners.

Failures observed in the Bates Road test resulted from relatively few load applications. But it was known that concrete is subject to fatigue — that is, even though concrete may withstand repeated stresses for a time, it may eventually break down if stress is applied a sufficient number of times. The fatigue characteristics of concrete beams were tested by Older, who reported the results to the American Society of Civil Engineers in 1924. He found that concrete beams would withstand an almost endless number of repetitions of a load if the tensile stress induced was less than 50 percent of the modulus of rupture. Some beams withstood more than 5 million repetitions. But Older also found that as loads were increased above the 50-percent limit the beams tended to fail under only a few thousand applications.

As a result of these tests, Mr. Older recommended that the value of S in the formula

$$d = \sqrt{\frac{3W}{S}}$$

be placed at 50 percent of the 733 value obtained from the Bates Road test. On this basis, a wheel load of 8,000 pounds (or its axle-load equivalent of 16,000 pounds) would require a pavement thickness of 8 inches.

This Illinois research had two rather prompt results: (1) The general adoption by States of the thickened-edge design of pavements, and (2) the general adoption of axle-load limitations. By 1926 most States were building pavements at least 8 inches thick at the edges, and most had adopted limitations as to axle load that were generally within the range of 15,000 to 18,000 pounds.

At about the time of this Illinois research, the Bureau of Public Roads began measurement of the impact force applied to roads by moving vehicles. It was found that this force is affected significantly by the speed of the vehicles and the type and condition of their tires. It was also learned that, for the same static load, solid rubber tires deliver greater impact than high-pressure pneumatic tires, which in turn deliver more impact than balloon tires. As the speed increased (up to 35 miles an hour) the impact increased for all types of tires.

In the Bates Road test (conducted in 1922-23) the test trucks were equipp with solid rubber tires and were operated at speeds of from 12 to 15 miles an hour. Assuming the Clifford Older theory to be correct, this type of use would require pavement 8 inches thick near the corners to withstand repeated applications of wheel loads of 8,000-pounds (equivalent to axle loads of 16,000 pounds) During the 1920's, a good deal of pavement was built to about 8-inch thickness.

By 1932 motortrucks generally were equipped with high-pressure pneumatic tires, but these vehicles were commonly driven at a speed of 40 miles an hour. The tests conducted by the Bureau of Public Roads suggested that the increase in impact caused by the higher speeds probably was offset by the change in tire type. Therefore, in 1932, the American Association of State Highway Officials (AASHO) recommended that all States adopt a 16,000-pound limit on axle loads for vehicles equipped with high-pressure pneumatic tires. At the same time the association acknowledged that research then current indicated that low-pressure pneumatic tires could carry 9,000-pound wheel loads (18,000 pounds per axle) without increasing stresses in pavement slabs.

By 1942 the use of balloon (low-pressure pneumatic) tires had become general. Therefore, particularly in view of the war emergency, the association raised its recommended limitation on axle loads to 18,000 pounds.

Experience has shown that warping action caused by temperature differentials probably is not so important in pavement deterioration as was originally supposed. A pavement that is well supported by a firm base should not act as a cantilever, hence it should not be subject to stresses such as those studied in connection with the Illinois tests. But pavements have deteriorated. Consequently, more recent research attention has been focused on the subgrade of pavements.

It is known that when a heavy wheel load is placed on a pavement slab, "The slab deflects under the point of load and rises slightly at points away from the load, up to 12 feet distance." 3/ Some flexibility in the subgrade is necessary for this action to occur. But the same action may permanently alter the conformation of the subgrade, particularly if the subgrade soils are sufficiently moist and are of such composition that they become plastic.

If enough moisture collects under the pavement, the phenomenon of "pumping" may result. That is, as the pavement deflects under the load its downward movement forces free moisture up through joints or cracks in the slab, or out from under its edge. If the subgrade is composed of materials that combine with moisture to form a thin mud, or slurry, then these subgrade materials also will be pumped out from under the pavement. 4/ When a pavement's subgrade support becomes uneven, the slabs are more susceptible to fatigue from heavy wheel loads.

If the theory developed as a result of the Illinois tests is correct, an 8-inch pavement should be able to withstand without damage an indefinite number of applications of axle loads of 18,000 pounds even if the subgrade support is uneven or otherwise defective. But the Highway Research Board reports that "... recent experiences indicate that the earlier concepts may no longer explain what happens to the pavements. For instance, a great mileage of existing pavements is probably close to the fatigue limit for usage by 18,000-pound axle loads." 5/

3/ Highway Research Board. The Truck Weight Problem in Highway Transportation. Bul. No. 26, p. 109. July 1950.

4/ For a discussion of subgrade moisture in relation to pavement cracking, see: Bleck, A. T. Pavements and Influences Affecting or Determining their Performance. Highway Res. Bd. Bul. No. 20. 1949.

5/ Highway Research Board. Bul. No. 26. Op. cit., p. 110.

It will be recalled that following the Bates Road test, pavements were commonly designed with a thickened-edge cross section. However, experience showed that most of the load failures in old pavements were found in the middle (and hence thinner) part of these slabs. The Highway Research Board has stated that "Within the last few years no less than half of the State highway departments have discontinued using thickened-edge slabs and adopted uniform thickness for slab cross section." 6/

Research and experience also have led to adoption of changes in design and construction of subgrades. "The use of granular material between the concrete pavement and the subgrade, has, in a very recent period become the common practice in a large number of States. It has been definitely demonstrated that granular materials placed over fine-grained or pumping soils will prevent pumping. The observed distress of old pavement, and a few of the newer ones, where heavy wartime truck traffic and the large military convoys were imposed upon them caused the highway engineers to question the adequacy of their designs. After study of the conditions the predominating conclusion was that the subgrades had not been properly treated or blanketed prior to placing of the concrete slab. There has not been complete agreement on the details of the analysis of the trouble nor on how to cope with it most economically. Among 40 or more States which presently require some kind of granular subbase, which may be anywhere from 4 inches to 15 inches in thickness, there is approximately a 2 to 1 preference shown in favor of using a porous readily drainable material rather than a dense graded relatively impervious layer." 7/

Assuming that, because of improvements in design, highways now under construction will be able to withstand heavy traffic, the problem of protecting pavements of older design remains.

In 1931, Thomas H. MacDonald of the Bureau of Public Roads stated that roads are more likely to be destroyed by climate and soil conditions than by any use that may be made of them. Although this statement was undoubtedly true at the time it was made, pavements are now deteriorating, partly because of the volume of heavy traffic now using the roads. 8/ The crucial question is this, How heavy is "heavy traffic?"

MacDonald in 1950 summed up the matter as follows: "Today, as in 1931, I can still say that our main roads are generally capable of withstanding 18,000-pound axle loads, and most of them are still safe for no greater load. But I cannot today exclude traffic loads as a cause of road damage. The reason lies in the great increase that has occurred in the number of vehicles with axle loads above, and far above, the design load of 18,000 pounds.

"In 1931, such excessive loads were occurring on no more than 8 axles in each thousand trucks. Today ....there are about 86 such excessive loads for

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6/ Highway Research Board. Bul. No. 26. Op. cit., p. 110.

7/ Ibid., pp. 110-11.

8/ For amplification and documentation of this statement, see statement of Thomas H. MacDonald, Part III, sec. 7 and appendices II and III, at hearings on Sen. Res. 50. Op. cit.

each thousand vehicles; and truck traffic volumes having increased about threefold in the interval, the increase in frequency of excessive loading has been of the order of 8 to 250, or over thirtyfold." 9/

Recent Research - Maryland Road Test

On June 6, 1950, an intensive test was begun on a section of concrete pavement forming a part of U. S. Route 301 south of LaPlata, Md. This project — known as Road Test One-MD — was proposed originally by the Interregional Council on Highway Transportation. It was conducted by the Highway Research Board in cooperation with 11 participating States and the Bureau of Public Roads. The object was to compare damage to roads caused by different axle loads.

Route 301 has two lanes, each 12 feet wide. The concrete is of thickened-edge design, having a cross-section 9 inches thick at the edges and 7 inches thick at the center. The road was built in 1941, and before the test it had been subjected to relatively light loads. At the time the test was begun, the pavement was remarkably free of visible damage.

A 1.1 mile section of the road was chosen for the test, and normal traffic was routed around it. The test section then was divided into two parts. On one lane of one part, 2-axle trucks were operated with rear-axle loads of 18,000 pounds. On the adjoining lane of the same part, similar vehicles carried rear-axle loads of 22,400 pounds.

On the other part of the test section, trucks with tandem axles were operated. In one lane the vehicles carried 32,000 pounds on the tandem axles, whereas in the adjoining lane trucks carried 44,800 pounds on these axles. These test trucks were scheduled to operate continuously for 6 months.

In figure 1 are shown results of Road Test One-MD for that part of the test pavement subjected to the different single axle loads. According to the original theory of design, the 18,000-pound axle loads should not have damaged the pavement. On the other hand, the 22,400 pound loads should have stressed the pavement slightly beyond its fatigue limit.

Figure 1 shows that the 18,000-pound loads damaged the pavement somewhat; but for an equivalent number of truck "passes" (axle-load applications), the 22,400-pound axle loads were associated with about 6 times as much damage. Damage was measured in terms of the number of lineal feet of cracks identified as structural failures.

In interpreting the results of this test, it must be remembered that although the data constitute evidence on the problem of highway preservation, that evidence cannot yet be considered conclusive. Additional tests are planned.

9/ Hearings on Sen. Res. 50. Op. cit., p. 981.

The relationship depicted in figure 1 was only one of several types of observations made in connection with the Maryland test. Other observations, primarily related to the subgrade, were summarized as follows:

"1. Soil tests made on samples obtained throughout the length of the pavement adjacent to the pavement edges and under certain sections of the pavement indicate that there is reasonable uniformity in the soils on the two sides of the pavement.

"2. Based on these same soil tests, there is found to be _a definite correlation between soil type and pavement behavior_. _The higher the granular content and the lower the plasticity of the soil, the better the performance_. The subgrade soils on this project are typical of the soils underlying a very extensive mileage of concrete pavement throughout the country.

"3. _The progress of cracking and depression of joints in the test sections has a definite relationship to the occurrence of pumping_. Previous research and observation have shown that four basic conditions must be present simultaneously to create a pumping slab. They are: (1) frequent heavy axle loads; (2) subgrade soils of such a nature that they may pump through open joints or cracks or at pavement edges; (3) free water under the pavement; and (4) joints or cracks in the pavement. These conditions were present on this project and pumping resulted.

"4. Based on both quality tests and dimension measurements, the concrete in the test sections is of good strength and of the designed thickness." 10/

In other words, results of the Maryland road test apparently confirm hypotheses relating pavement damage to the condition of the subgrade.

Minnesota Bearing Test.- Particularly in the northern States, the action of frost affects the condition of roads. In winter, freezing occurs to a depth of several feet. This frozen subbase provides a firm support for a surfaced road, and makes its load-bearing capacity high. 11/ On the other hand, the period of thawing, or spring break-up, as it is commonly termed, is a critical period for highways in the northern States. Soil moisture is abundant at this time, and subgrades of surfaced roads lose much of their supporting ability. When this condition occurs, the load-bearing capacity of a road is relatively low.

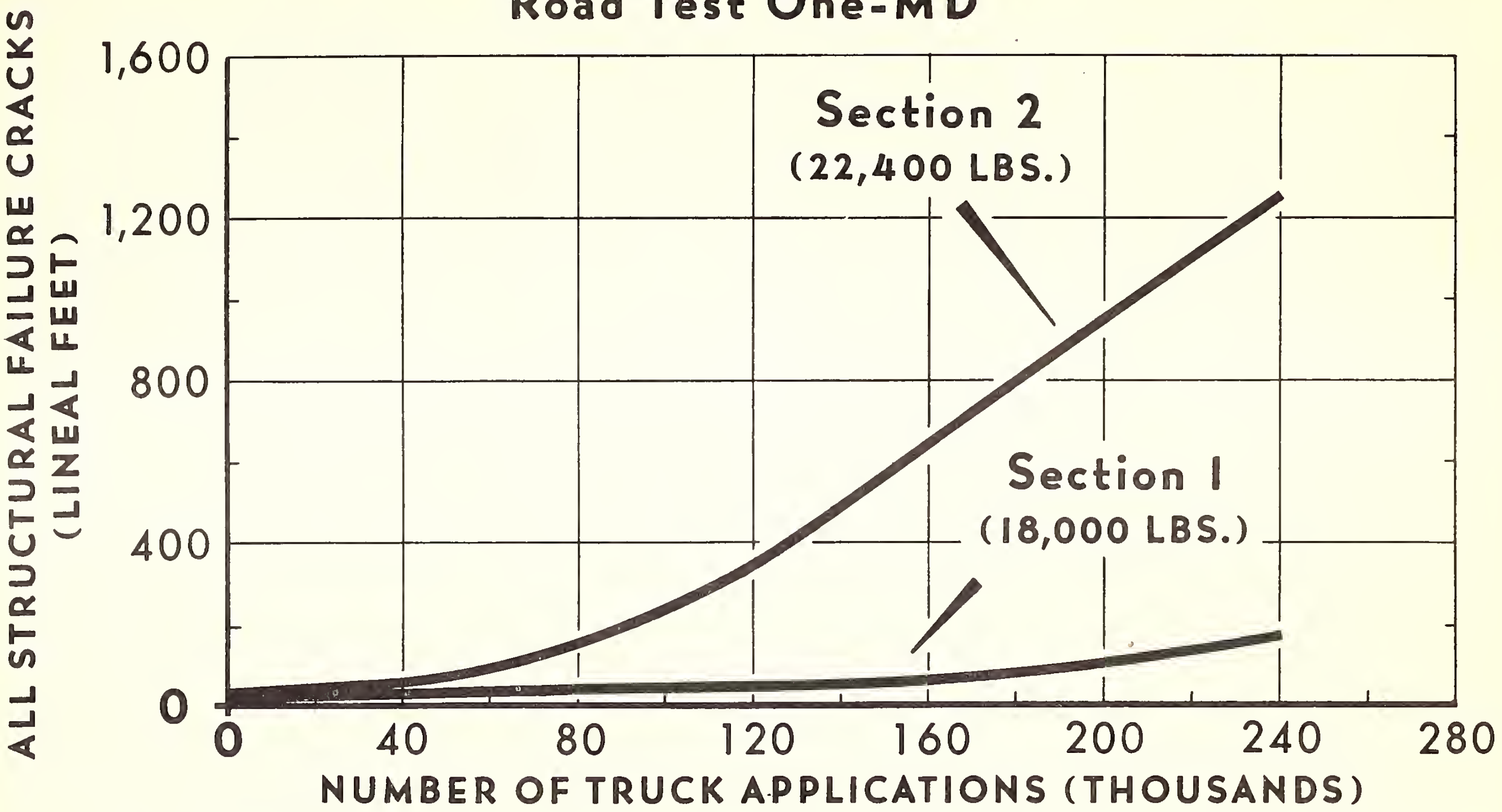
Because of location, the action of frost was not a significant variable in the observations made in the Maryland road test. However, a committee of the Highway Research Board has been conducting seasonal tests in cooperation with eight northern States. Although these tests are still in progress, the 1950 Minnesota report indicates preliminary results as follows:

10/ Highway Research Board. Report of Progress on Road Test One-MD., p. 2 Jan. 11, 1951. (Italics added.)

11/ Highway damage may result from frost heaving.

RATE OF CRACK DEVELOPMENT UNDER SINGLE AXLE LOADS

Road Test One-MD



*DATA FROM ROAD TEST ONE-MD, HIGHWAY RESEARCH BOARD REPORT NO. 9, FIG. 1, P. 10 (MAY 1951)
CRACKS ARE THOSE WHICH HAVE BEEN ANALYZED AS CONSTITUTING STRUCTURAL
FAILURES DUE TO THE APPLICATION OF TEST AXLE LOADS*

U. S. DEPARTMENT OF AGRICULTURE NEG. 48866-X BUREAU OF AGRICULTURAL ECONOMICS

Figure 1.

"In each year (for 3 successive years) abrupt springtime strength loss of about 50 percent is followed by gradual recovery. In the tests it has also been observed that there is close similarity of loss of strength values secured when loading (a) the top of the roadway, (b) the top of the stabilized gravel base, and (c) the top of the subgrade." 12/

Results of the Minnesota test, presented graphically in figure 2, show that after the abrupt decline in load-bearing capacity during the period of thawing, the road strength recovered steadily up to the time of hard freezing.

In his preliminary report in 1948, C. L. Motl, Maintenance Engineer of the Minnesota Department of Highways and Chairman of the committee of the Highway Research Board conducting the study of frost action, said:

"It appears that many miles of highways now in the process of deteriorating under traffic very likely suffered their initial and serious damage during the spring of the year, even though it may not have been immediately apparent.

"It is further indicated that the desired practice of a uniform road policy throughout the year in the frost belt may be economically unsound. With the possible exception of limited and extremely important mileage of highways, road investments could probably be more fully utilized by seasonal changes in road limits in harmony with the ability of soils and road bases to support the loads." 13/

To deal with this problem, a few States in the frost belt reduce the loads allowed during the so-called spring break-up. For a time Wisconsin made use of a road classification that took account of the reduced load capacity of its roads in spring.

Weight Limitations Related to Axle Spacings

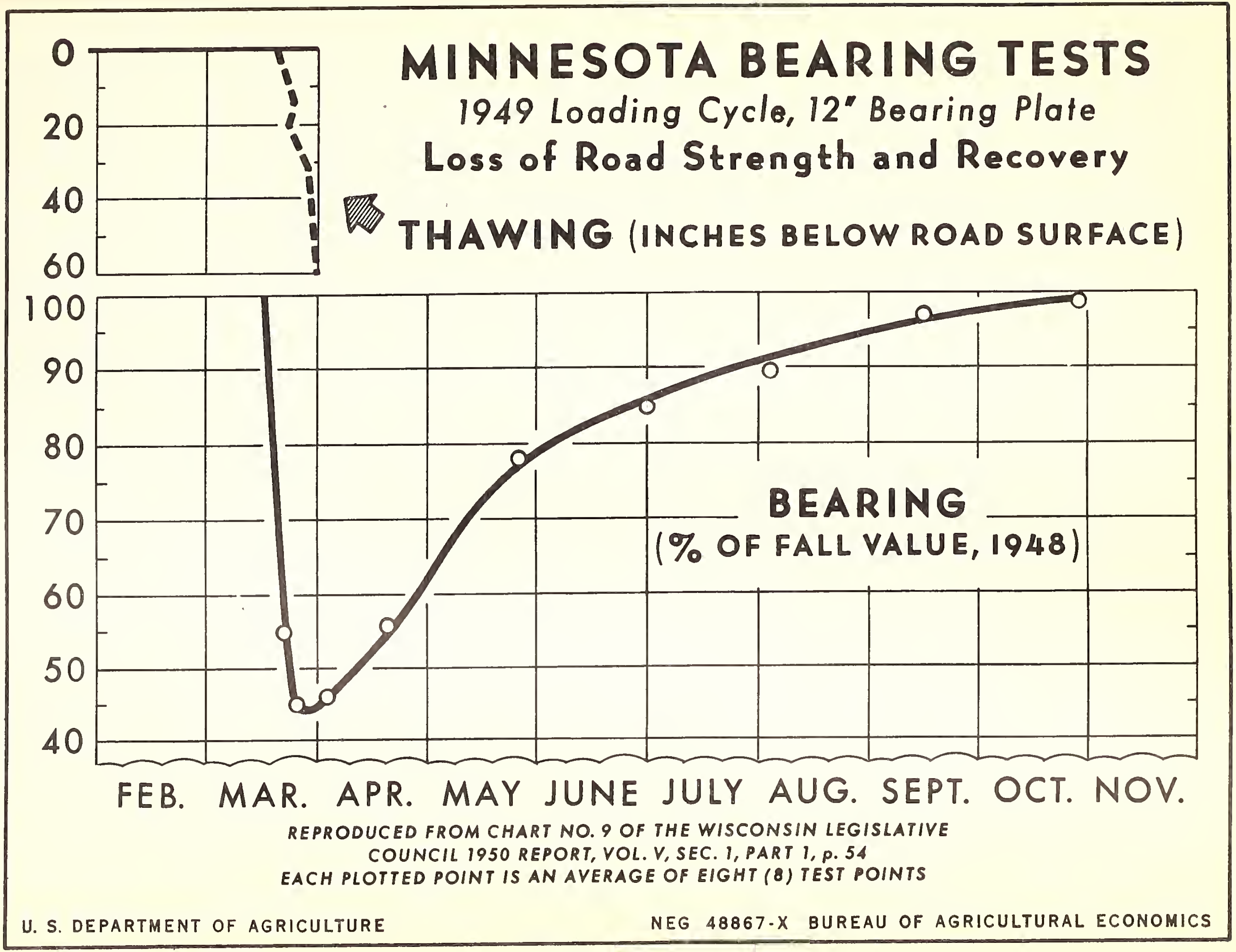
Bridges 14/

In 1931 a "standard" vehicle was adopted by the American Association of State Highway Officials to form the basis of bridge design. This standard vehicle was defined as having two axles spaced 14 feet apart, with a load of 6,000 pounds on one axle and 24,000 pounds on the other, or a total gross weight of 15 tons. A bridge designed to serve such a vehicle was designated as an H-15 bridge. Today this type of bridge predominates on the main road systems of the United States.

12/ Highway Research Board. Load-Carrying Capacity of Roads as Affected by Frost Action. Res. Rept. No. 10-D, pp. 8-9. 1950.

13/ Highway Research Board. Proceedings of 28th Annual Meeting, pp. 280-81, 1948.

14/ Material in this section is based on Part IV of statement of Thomas H. MacDonald at hearings on Sen. Res. 50. Op. cit., pp. 984 ff.



MINNESOTA BEARING TESTS

1949 Loading Cycle, 12" Bearing Plate

Loss of Road Strength and Recovery

REPRODUCED FROM CHART NO. 9 OF THE WISCONSIN LEGISLATIVE COUNCIL 1950 REPORT, VOL. V, SEC. 1, PART 1, p. 54

EACH PLOTTED POINT IS AN AVERAGE OF EIGHT (8) TEST POINTS

U. S. DEPARTMENT OF AGRICULTURE NEG 48867-X BUREAU OF AGRICULTURAL ECONOMICS

Figure 2.

During the 1920's, when most vehicles had only two axles, and when the wheel base of heavy vehicles was relatively uniform, a single maximum limitation on the gross weight of vehicles was thought to be sufficient to protect bridges. But around 1930 vehicle combinations (tractor-semitrailers, for example) were becoming more common. Such a vehicle generally has a greater gross weight, more axles, greater over-all length, and axle spacings that vary from the typical vehicle of the 1920's.

It is known that, for a given gross weight of a vehicle, bridge stresses vary with varying lengths of the vehicle. That is, a short vehicle tends to generate greater stresses in a bridge than does a longer vehicle of the same weight. To take this relationship into account, the AASHO recommended in 1932 that the following formula be considered by the States for the protection of their bridges:

$$W = C\,(L + 40)$$

in which

W = the permissible gross weight of the vehicle in pounds

L = the distance in feet between the first and last axles of the vehicle

C = a coefficient to be set at a value consistent with the general strength and condition of the bridges of a State

Eventually most States adopted variations of this formula. These variations, however, were not uniform. Moreover, many people regarded a mathematical formula as an impractical device for limiting the weights of vehicles.

Because of these difficulties, the AASHO set about constructing a table of weights to replace the formula. The weight values in the table were to be safe for H-15 bridges, but not unduly restrictive for the loads carried by common types of vehicles. The values in table 1 were recommended by the association in 1946. Although the tabular weight values did not differ substantially from the formula values of several of the States, the table had the advantage of simplicity, a major assistance both in designing vehicles and in enforcing the law. In addition, the table encouraged uniformity in the regulations of the various States.

It will be recalled that the formula recommended in 1932 by the AASHO applied only to the total gross weight of the vehicle as it was related to the distance between the foremost and the rearmost axles of the vehicle. However, the values in the table were to apply to interior groups of axles, as well as to the over-all wheel base. That is, the table was intended to set a maximum on the gross weight that could be carried on any possible combination of axles in relation to the distance between the foremost and rearmost axles of the particular group under consideration.

Table 1.- Maximum load that may be carried by motor vehicles, April 1, 1946 1/

By axle spacings

Spacing between axles	Maximum combined load	Spacing between axles	Maximum combined load
Feet	Pounds	Feet	Pounds
4	32,000	31	53,490
5	32,000	32	54,330
6	32,000	33	55,160
7	32,000	34	55,980
8	32,610	35	56,800
9	33,580	36	57,610
10	34,550	37	58,420
11	35,510	38	59,220
12	36,470	39	60,010
13	37,420	40	60,800
14	38,360	41	61,580
15	39,300	42	62,360
16	40,230	43	63,130
17	41,160	44	63,890
18	42,080	45	64,650
19	42,990	46	65,400
20	43,900	47	66,150
21	44,800	48	66,890
22	45,700	49	67,620
23	46,590	50	68,350
24	47,470	51	69,070
25	48,350	52	69,790
26	49,220	53	70,500
27	50,090	54	71,200
28	50,950	55	71,900
29	51,800	56	72,590
30	52,650	57	73,280

1/ Recommended by American Association of State Highway Officials, April 1, 1946.

The various axle combinations for a 4-axle vehicle are illustrated in figure 3.

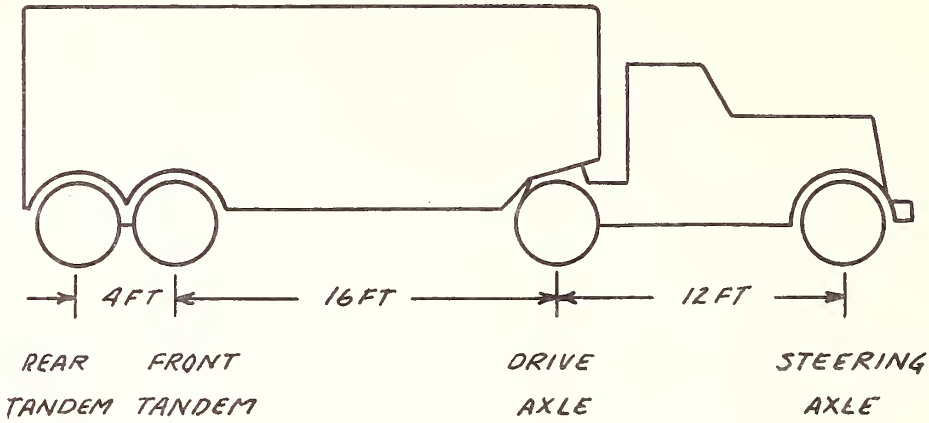


Figure 3. - Axle combinations on a 4-axle vehicle

The 1945 class A bridge formula would allow the following maximum weights on each axle combination of the 4-axle vehicle illustrated above:

A. Distance between foremost and rearmost axles of vehicle
26,000 + [1000 x 32] = 58,000 pounds

B. Distance between steering axle and front axle of tandem axle group
26,000 + [1000 x 28] = 54,000 pounds

C. Distance between front and rear axles of tandem axle group
26,000 + [1000 x 4] = 30,000 pounds

D. Distance between steering axle and drive axle of vehicle
26,000 + [1000 x 12] = 38,000 pounds

E. Distance between drive axle and rear axle of tandem axle group
26,000 + [1000 x 20] = 46,000 pounds

F. Distance between drive axle and front axle of tandem axle group
26,000 + [1000 x 16] = 42,000 pounds

Under Wisconsin's 1945 class A law, a 4-axle vehicle would have to meet all of the above weight restrictions, plus the limitation of 19,000 pounds maximum on each of the four axles. Hence, a trucker could be arrested for a weight violation on any of these counts. In practice, however, axle combinations B, D, and F seldom have loads even as large as those specified in the table. The table, however, can easily set effective load limits on axle combinations A, C, and E.

Pavements

Even though the weights listed in the AASHO table originally were determined in relation to the designed-capacity of H-15 bridges, nevertheless the relation of axle spacings to pavement damage is also important. If the subgrade support under a rigid pavement is uneven, a pavement slab acts as a type of bridge. It should be borne in mind, however, that stresses induced in such a "bridge" need not closely resemble those induced in an H-15 bridge. In any case, considerable interest now is focused on the relation between interior axle spacings and damage to pavement slabs.

Among the various interior combinations of axles on trucks, tandem axles (that is, two axles separated by a distance of approximately 4 feet) have received most of the research attention. In the table recommended by the AASHO in 1946, these axles were allowed a combined load of 32,000 pounds.

In the Maryland road test, one part of the test section was devoted to testing the relative damage associated with different loads on tandem axles. On one lane, trucks were operated with a 32,000-pound load on the tandem axles, whereas in the adjoining lane the trucks carried 44,800 pounds on tandem axles.

Figure 4 shows that for an equivalent number of applications ("passes") the 44,800-pound tandem axles were associated with an average of approximately 11 times as much cracking (measured in lineal feet) as were the 32,000-pound tandems. After 92,166 passes by the trucks, the lane subjected to 44,800-pound loads became so rough that this part of the test was discontinued. On the adjoining lane, trucks with 32,000-pound tandem axle loads continued to be operated until driving on all test lanes was terminated in December 1950, when tandem axles carrying 32,000-pound loads had been applied 160,000 times.

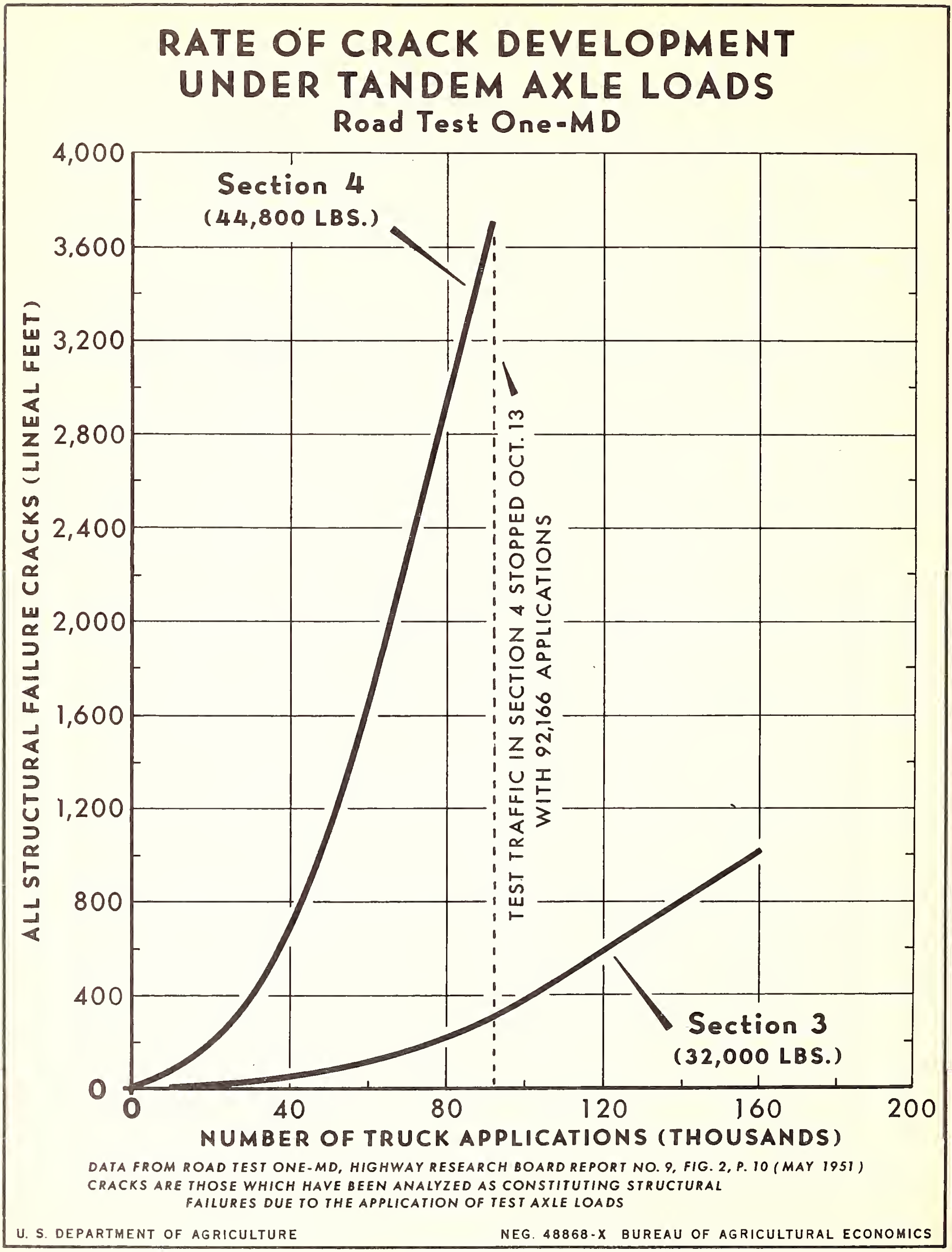
A result of the Maryland test that was somewhat surprising was the relative damage associated with tandem axles as compared to single axles. Figure 5 shows this comparison.

It might have been expected that, for the same number of truck passes, the damage associated with 32,000-pound tandem axles would be approximately twice that associated with 18,000-pound single axles, inasmuch as for an equivalent number of truck passes a vehicle with tandem axles applies twice the number of heavy axles 15/ as does a vehicle with a single axle in the rear. 16/ Results, however, did not correspond to such an expectation. Figure 5 shows that after 160,000 truck "passes" in each case, the 32,000-pound tandem axles were associated with about 10 times as much pavement cracking as that associated with 18,000-pound single axles. This comparison may not be strictly valid because these two test lanes were not adjacent, and hence their subgrades may have been dissimilar. But at least these results suggest the hypothesis that

---

15/ Front axles (that is, steering axles) are not considered to be heavy axles, and only negligible damage is attributed to their application.

16/ This assumes that the damage induced per application of each axle is equivalent for a load of 18,000 pounds on a single axle as compared to a load of 16,000 pounds on one of the two axles of a tandem.



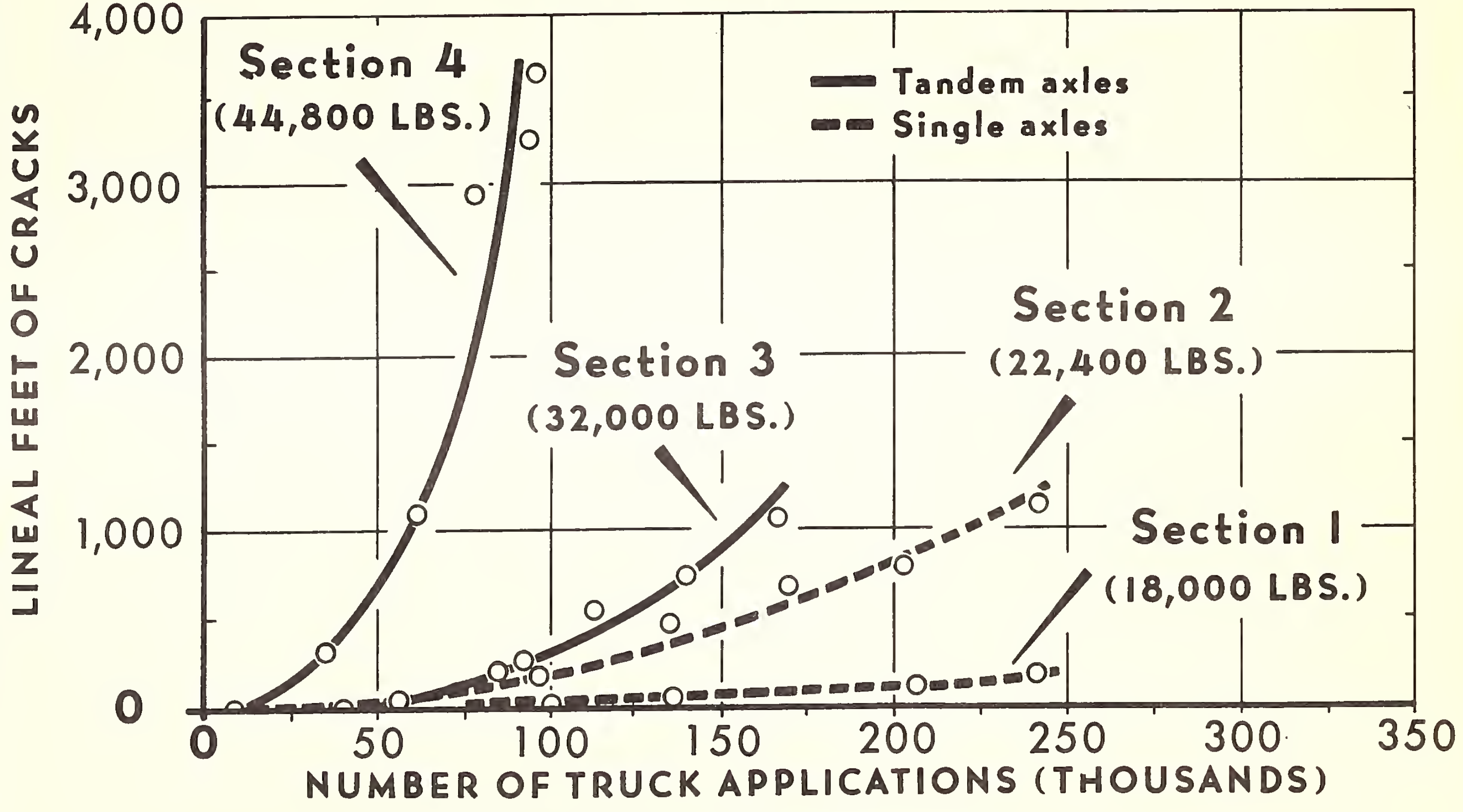
RATE OF CRACK DEVELOPMENT UNDER TANDEM AXLE LOADS

Road Test One-MD

DATA FROM ROAD TEST ONE-MD, HIGHWAY RESEARCH BOARD REPORT NO. 9, FIG. 2, P. 10 (MAY 1951)
CRACKS ARE THOSE WHICH HAVE BEEN ANALYZED AS CONSTITUTING STRUCTURAL FAILURES DUE TO THE APPLICATION OF TEST AXLE LOADS

U. S. DEPARTMENT OF AGRICULTURE NEG. 48868-X BUREAU OF AGRICULTURAL ECONOMICS

Figure 4.



RATE OF CRACK DEVELOPMENT, TANDEM AXLES COMPARED TO SINGLE

Road Test One-MD

DATA FROM FIGURES 1 AND 4 OF THIS REPORT

U. S. DEPARTMENT OF AGRICULTURE

NEG 48869-X BUREAU OF AGRICULTURAL ECONOMICS

Figure 5.

a 16,000-pound axle load in a tandem combination causes more damage than an 18,000-pound single-axle load. Additional tests may shed more light on this question.

During 1950, the Wisconsin State Highway Commission conducted a number of tests to show the comparative deflections 17/ of rigid pavement slabs when subjected to single and tandem-axle loads at various speeds. The following are the composite results of seven preliminary tests:

"1. At creep speeds (5 m.p.h.) the single axle (19,000 pounds) showed greater deflections than the tandem axles (30,820 pounds).

"2. At low and medium speeds (15 to 35 m.p.h.) the tandem axles caused deflections 20 to 50 percent greater than the single axle.

"3. At high speeds (50 to 55 m.p.h.) the tandem axles caused, on the average, twice the deflection of the single axle." 18/

The Wisconsin research indicates that, particularly at high speeds, tandem axles carrying 31,000 pounds deliver to the pavement a much greater impact (measured by pavement deflection) than does a single axle carrying 19,000 pounds. Obviously, deflection of slabs directly affects the pumping action of pavements, and the Maryland road test indicates that a definite relationship exists between pumping and pavement cracking.

Concrete pavement slabs possess some flexibility, and when their subgrade support is plastic or uneven, it seems likely that a heavy axle application might induce a type of whipping action in the slab. When such a slab is subjected to the simultaneous application of several axles, all moving at high speeds, the ensuing action of the slab is not obvious. But it seems likely that the slab stresses would differ from those induced by the repeated application of a load on an unsupported end of a concrete beam.

The Maryland road test apparently supports the hypothesis that an axle spacing as narrow as 4 feet (the usual distance between tandem axles) has a significant relation to pavement damage when the combined load is at least 32,000 pounds. Unfortunately, none of the tests shed much light on the comparative effect of different axle spacings in excess of 4 feet.

In any case, it seems likely that the effect of different axle spacings on pavement slabs may differ from the effect of the same axle spacings on H-15 bridges. As we have seen, the latter forms the basis for the axle weights and spacing recommendations listed in the AASHO table approved in 1946.

17/ As used here the term "deflection" means the distance that the end of a concrete slab was depressed from its normal position because of a weight application at that point.

18/ See: Public Roads Administration. Liberalization of State Limitations of Sizes and Weights of Motor Vehicles. July 20, 1942. (Processed.)

WISCONSIN TRUCK WEIGHT RESTRICTIONS AND THE DAIRY INDUSTRY

As pointed out earlier in this report, restrictions as to truck weights have a two-sided effect. First, they tend to hold down public expenditures for construction and maintenance of a given system of roads. Second, they tend to raise the cost of truck transportation, and this increase in cost affects trade in general.

The preceding section examined the basis of weight restrictions on trucks. The purpose was to gain an appreciation of the value in preserving highways of the different types of limitations on the weights of vehicles. This section examines Wisconsin's truck weight laws and their application to part of the dairy industry's transportation system. This is to discover the costs that the different types of restrictions can impose upon trade.

Truck Transportation of Wisconsin Fluid Dairy Products

Wisconsin fluid dairy products move through three distinct stages: (1) Milk moves from farms to dairy plants, (2) fluid products move between plants in the State, and (3) milk moves to out-of-State markets. Motortrucks supply almost all of these transportation services. The structure of the Wisconsin dairy industry has evolved on a basis of truck transportation coupled with the economic forces that underlie the processing of milk.

When the horse and wagon was the mode of transportation from farm to plant, it is probable that the haul rarely exceeded 5 miles. The size of a dairy plant was limited by the small territory from which it could procure milk. Hence, the Wisconsin dairy industry consisted of very small plants, and because the industry was already widely developed, there were many such plants.

Many processes of dairy manufacturing are subject, however, to economies of large-scale production. That is, the cost per unit of output can be reduced if the volume of output can be increased. So an economic incentive existed for the small plants to obtain larger supplies of milk. The use of motortrucks made this possible.

The route truck replaced the horse and wagon in farm-to-plant hauling. Instead of each farmer transporting his own milk to the plant, the farms were grouped into routes. Each day a truck "made the rounds" of the patrons on its route, collected the milk, and delivered it to the plant. As time passed, progressively larger route trucks were used to carry more milk over greater distances. This enabled the plants to compete for the existing milk supply. In the long run the more efficient plants could bid the milk away from the less efficient. Because the latter could not pay the competitive price, they gradually went out of business, and their milk was diverted to the more efficient processors. Thus was established the basic trend that characterized the evolution of the present dairy industry in Wisconsin -- the trend toward progressively fewer, larger, and more efficient plants.

Other types of truck hauling stimulated this trend. Increasing quantities of milk and other fluid dairy products were transported between plants in Wisconsin, mostly in tank trucks. When large quantities of milk and considerable distances are involved, tank trucks are a more economical method of transportation than the smaller route trucks used to haul milk from farm to plant. Hence, tank trucks widened further the area of supply available to dairy plants, enabling them to become even larger. In this way, huge multiple-operation plants were supplied from a number of outlying receiving stations which were themselves supplied by route trucks. In other instances, byproducts of certain types of dairy manufacture were tanked from the plants in which they originated to large specialized processing plants.

In addition, increasing quantities of milk were shipped from Wisconsin to out-of-State markets. Most of this milk also moved by tank truck. The greater part went to Chicago although some moved farther south. The Wisconsin dairy industry was particularly sensitive regarding this milk because it was utilized in distribution by bottle, which is the market of highest profit for the State's milk.

World War II accelerated most of the basic trends in the industry. The rate of plant consolidation increased markedly, and the volume of out-of-State shipments soared. The industry's use of truck transportation facilities increased accordingly. Because the State did not enforce its restrictions on truck weights during this period, the trend toward larger trucks went unchecked.

This trend toward larger trucks also had an economic foundation. Generally, for a trip of a given distance, hauling costs per unit of product tend to decline if a larger quantity of product is carried.

We have seen that if a plant is able to obtain additional quantities of milk, plant processing costs per unit of output tend to decline. However, if additional milk can be obtained only by sending trucks over progressively greater distances, then procurement costs per unit of output tend to rise. Eventually a point is reached at which for an additional volume of milk, the rise in cost of procurement offsets the decline in processing cost. It is not economical for a plant to expand beyond this point, but often more economical transportation enables a plant to reach a greater size before this point is reached. Therefore, progressively larger trucks were used both for farm to plant hauling and for interplant hauling within the State.

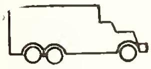
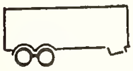
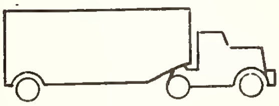
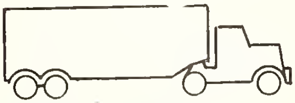
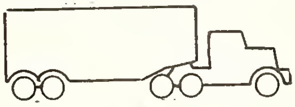
The trend toward use of larger trucks was also noticeable in out-of-State shipments. The competitive price for milk is the delivered price, and for out-of-State shipments the transportation cost is relatively high. If the trucking cost per unit of product can be reduced, the industry can compete for markets over a wider area. Hence, the industry tended to use trucks as large as could be operated legally.

History of Wisconsin Truck-Weight Restrictions

Load Limits before World War II

In 1924, Wisconsin imposed a limitation of 19,000 pounds on the load that could be carried by any individual axle of a vehicle. This regulation was still in force when the United States entered World War II, although by that time several other regulations had been added. The law directed the highway commission to classify the State's highways as A or B. The commission was allowed to use its judgment as to which roads to classify as B, the criterion being the ability of the road to carry heavy traffic. All other State highways were automatically classed as A. The classification was flexible. For example, certain roads classed as B during the spring break-up were shifted to the A class during the remainder of the year. Table 2 shows the regulations that applied to these two classes of roads in 1941.

Table 2. - Restrictions on weight of motortrucks in Wisconsin, 1941

Type		Highway	
		Class A	Class B
		Pounds	Pounds
Maximum weight allowed		19,000	12,000
Any individual axle			
Single-unit two-axle vehicle		24,000	15,000
Single-unit vehicle having tandem drive axles		36,000	22,500
Tandem axles of semitrailers		24,000	15,000
Semitrailer combinations			
Three-axle		1/ 43,000	
Four-axle		2/ 48,000	
Five-axle		3/ 60,000	

1/ 19,000 pounds plus 24,000 pounds.
2/ 24,000 pounds plus 24,000 pounds.
3/ 24,000 pounds plus 36,000 pounds.

Wisconsin Statutes, 1941.

Although no tolerance was specified in the law, it was the policy of enforcement officials to grant a tolerance of 5 percent to allow for such things as inaccurate weighing, shifting of loads, and accumulations of mud or ice on the vehicle. Thus, the limits including tolerance were 5 percent in excess of the statutory limits as shown.

Load limits during World War II

As a defense measure in 1942, at the request of the Federal Government, the Council of State Governments urged the acceptance by States of more liberal regulations governing the sizes and weights of motor vehicles. In response, Wisconsin suspended the enforcement of those size and weight limitations that were lower than the ones proposed by the council. 19/

In 1943 State legislation was passed which was to supersede for the duration of the war emergency some of the statutory weight limitations in effect at the outbreak of hostilities. The following class A highway limits were changed: The gross weight maximum for a single-unit 2-axle vehicle was raised from 24,000 to 30,000 pounds. The gross weight maximum for a single-unit vehicle having tandem-drive axles was raised from 36,000 to 40,000 pounds. The maximum weight allowed on the tandem axles of a semitrailer was raised from 24,000 to 30,000 pounds. Although the gross-weight limitations for combination vehicles were raised accordingly, the maximum load allowed on an individual axle remained at 19,000 pounds.

The 1945 Law

In 1945 the Wisconsin legislature enacted new regulations shown in table 3.

Table 3. - Restrictions on weight of motortrucks in Wisconsin, 1945

Type of regulation	Highway	
	Class A	Class B
	Pounds	Pounds
Maximum load allowed on		
Any individual axle	19,000	12,000
Any combination of axles	26,000 + 1,000L 1/	16,000 + 600L 1/

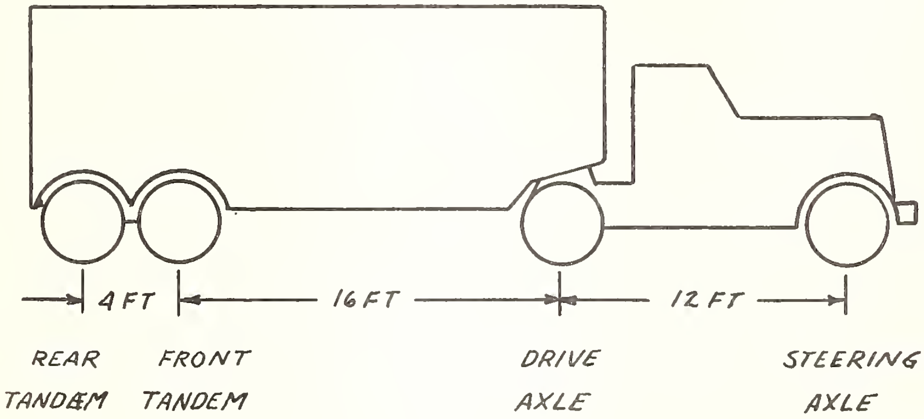
1/ L is the distance in feet between the first and last axles of the vehicle.

19/ Wisconsin Statutes. 1945. 85.47(1).

The new law retained the individual axle-load limitations at their previous levels, but introduced so-called "bridge formulas" which related axle spacings to the maximum gross weight allowed on combinations of axles.

The symbol 26,000 + [1000 x L] is explained by the wording of the law: "The gross weight on any two or more axles shall not exceed 26,000 pounds plus 1,000 pounds for each foot of distance measured longitudinally to the nearest foot between the foremost and the rearmost of the axles under consideration." 20/

The application of the class "A" bridge formula may be illustrated for a hypothetical four-axle semitrailer combination vehicle with tandem axles on the semitrailer.



The over-all gross weight permitted this vehicle would be determined by the distance between the foremost and rearmost of the 4 axles (4 + 16 + 12 = 32 feet). The class A bridge formula would set a gross weight maximum for vehicles of 26,000 + [1000 x 32] = 58,000 pounds.

The gross weight permitted on the axle combination consisting of the drive axle and the two tandem axles would be determined by the distance between the rear tandem and the drive axle (4 + 16 = 20 feet). The formula would allow a maximum of 26,000 + [1000 x 20] = 46,000 pounds on this combination of three axles.

The gross weight allowed on the tandem axles would be determined by the distance between them (4 feet). The formula would allow 26,000 + [1000 x 4] = 30,000 pounds on these axles. 21/

If this vehicle carried the legal 30,000 pounds on the tandem axles, the maximum legal load on the drive axle would be 16,000 pounds, as the bridge

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20/ 1945 Wisconsin Statutes, 85.47 (1).

21/ Wisconsin Highway Commission. State Highway Activities, p. 61, 17th Biennial Report. 1948.

formula would limit the combined load on those 3 axles to 46,000 pounds. Thus, even though in general an individual axle may be allowed a maximum of 19,000 pounds, for this hypothetical vehicle the bridge formula would prevent the drive axle from carrying that much weight. In order to carry 19,000 pounds on the drive axle, the distance from the rear tandem to the drive axle would have to be increased from 20 to 23 feet. This would raise the bridge formula maximum to 49,000 pounds for those 3 axles, and the truck then could carry 30,000 pounds on the tandem axles and 19,000 pounds on the drive axle.

For a vehicle of the type under consideration, the maximum practical load on the steering axle would be approximately 8,000 pounds. Thus, for the hypothetical vehicle, the practical maximum gross weight would be the 46,000 pounds allowed on the last 3 axles by the bridge formula, plus the practical maximum of 8,000 pounds on the steering axle. This would provide a practical maximum gross weight for the vehicle of 54,000 pounds, even though (as shown previously) the bridge formula would allow a theoretical 58,000-pound weight for the entire vehicle.

In administering the 1945 law, enforcement officials adopted the following general policy with regard to tolerance: In connection with the statutory 19,000-pound limitation on the weight carried on an individual axle, a tolerance of 1,000 pounds was granted. In connection with the bridge formula, a tolerance of 2,000 pounds was granted for axle combinations in which the distance from the foremost to the rearmost of the axles under consideration was 12 feet or less. If the distance was greater than 12 feet, a tolerance of 3,000 pounds was allowed for the combination under consideration.

The 1945 regulations made illegal the capacity operation of much transportation equipment in use at that time. Tank trucks hauling fluid dairy products, as well as dump trucks, were especially hard hit by the bridge formula. Enforcement of the new law lagged for a time and then stiffened; but in 1948 the highway commission made the following statement:

"Restrictions on loads carried on our highways were not enforced during the war, nor have they been adequately enforced since the war. Today it is a somewhat general practice for a large number of trucks using the highways to be overloaded, and as a result, many of our main traveled routes are deteriorating at a rapid rate." 22/ The records for 1948 show that the 4-axle semi-trailer combination vehicles were especially serious violaters.

The 1949 Amendment

The 1949 legislature passed an amendment that accorded to dump trucks and tank trucks carrying milk, several temporary increases in maximum allowable weights. The legislative purpose was expressed as follows:

"In the enactment of this act, the legislature hereby declares that the special weight limitations provided in this act are in recognition of the emergency created by the special weight limitations authorized during the war emergency whereunder vehicles designed for such increased weights were purchased

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22/ Wisconsin Statutes. 1949. c.396(5).

and used. It is recognized that the highway system of Wisconsin is not adequate to sustain such increased weight limitations for an extended period of time, and it is critically necessary that weight limitations be stabilized at or near limits provided by statutes heretofore in force. The legislature further declares that its purpose in setting June 30, 1951 as the expiration date of the emergency weight limits is to permit the various industries concerned, having and using such special vehicles, to convert their present equipment or to acquire new equipment in keeping with the basic standards of weight limitations prescribed by statute." 23/

Emergency weight limits authorized in the 1949 amendment provided two weight increases for tank trucks hauling fluid dairy products: (1) An increase in the class B limits up to the levels specified for class A in the 1945 law, and (2) an increase in the class A bridge formula which changed it to 26,000 + [2,000 x L]. The class A load limit for an individual axle remained unchanged at 19,000 pounds.

It was specified that the liberalized provisions applied only to vehicles registered before the effective date of the amendment, and only to those milk tankers that had gross vehicle weights of 28½ tons or less. 24/ These special provisions were to terminate on June 30, 1951.

A major problem facing the 1951 legislature was a review of the full force and effect of the 1945 law, vigorously enforced, after the expiration of the emergency provisions of the 1949 amendment.

Effect of the 1945 Class B Weight Limits on the Marketing of Wisconsin Fluid Dairy Products and Changes in Limits, 1950 and 1951

Vigorous enforcement of the 1945 class B weight limits would have impinged upon the marketing of fluid dairy products primarily at two stages: (1) Farm-to-plant hauling, and (2) interplant hauling for which either the sending or the receiving plant was located off the main highway system.

Farm-to-plant hauling

Use of route trucks for farm-to-plant transportation was instrumental in shaping the evolution of the dairy industry. In 1949 almost 6,000 of these route trucks operated in Wisconsin. Most of them were single-unit 2-axle vans with dual wheels in the rear.

In the farm-to-plant phase of the marketing of milk, the product is handled in 10-gallon cans. The route trucks are classed according to the number of cans that their racks will hold, most of them having 66-, 72-, 78-,

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23/ Laws of Wisconsin (1949) c. 396 (5).

24/ Dump trucks were accorded the same liberalized class A provisions in the 1949 amendment, except that to qualify for the emergency provisions, their gross vehicle weight was required to be 25 tons or less. The emergency class B provisions for dump trucks differed somewhat from those applying to milk tankers.

or 84-can bottom racks. 25/ These numbers do not indicate the effective capacities of the trucks since the cans may be double-decked up to the last two rows. Thus a truck with a 72-can bottom rack may carry 120 or more cans of milk.

Table 4 shows the axle loads of route trucks of the modal, the average, and the largest sizes, when they are loaded to their respective capacities. All of the rear-axle loads exceed the 1945 class B limit of 12,000 pounds. Compliance with the class B limit would reduce the effective capacity of the "66" size by 10 to 15 percent, the capacity of the "72" size would be reduced by 30 to 35 percent, and the capacity of the "84" size would be reduced by about 50 percent.

Table 4. - Axle loads of route trucks loaded to capacity with cans of milk

Size of bottom rack	Approximate effective capacity	Load on	
		Front axle	Rear axle
Cans	Cans	Pounds	Pounds
66	108	2,500 - 3,500	13,000 - 14,000
72	120	3,000 - 4,000	15,000 - 16,000
84	144	5,000 - 6,000	18,000 - 19,000

During fall and winter all the milk on most routes can be collected by the truck on one trip. However, milk production on many routes in spring and early summer exceeds the capacity of the truck, and requires two trips a day. If the capacity of the route truck is reduced, the effect is to lengthen the period of the year during which two trips a day are necessary. Obviously, two trips a day on a route require more miles of travel than does one trip. Since the number of miles of travel affects the total cost of trucking, the effect of a reduction in truck capacity would be an increase in the annual cost of collecting the milk on a route. 26/

The general manager of a large cooperative plant that operates its own trucks testified at a legislative hearing, 27/ that the cost of hauling milk from farms to his plant would be increased by about 25 percent if the company

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25/ The modal size is 66, but because the distribution is skewed upward the average size is 72. The composite effect of the law on all four sizes appears to be reasonably well represented by the law's application to the average (72) size.

26/ Although total trucking costs are a function of the size of the payload that is carried on a given trip, truckers agree that an increase in payload does not result in a proportional increase in total costs.

27/ Report of public hearing on the transportation problems of the Wisconsin dairy industry, before the Highway Advisory Committee of the Wisconsin Legislative Council, June 5, 1950.

were forced to change from the "84" size route truck to the "62" size. For the State as a whole, however, confidential estimates of the better informed members of the industry show that compliance with class B load limits would increase hauling costs in the neighborhood of 5 percent.

Interplant hauling

The hauling of fluid dairy products, co-products, and byproducts between plants in Wisconsin is an important element in the pattern of dairy marketing. In 1949 the quantity of these products hauled between plants amounted to one-third of the weight of milk delivered to plants directly from farms. In turn, approximately one-third of this hauling was accounted for by the movement of whey from cheese factories to central drying plants.

Vigorous enforcement of the class B weight limits specified in the 1945 law would affect the whey-drying industry in Wisconsin. One of the larger whey-drying companies in the State made a detailed survey of its hauling operations, and the following representative data were presented at a legislative hearing. 28/

In the survey it was found that 32 percent of the whey was collected from cheese factories located on class A highways, 29/ and 68 percent was obtained from factories located on class B highways and secondary roads. But these percentages do not tell the whole story. Most of the trips require pick-ups from more than one cheese factory. In a sample of 1,771 trips, 30/ 3 pick-ups were made per trip, on the average. Thus, an average trip might require travel on class B roads, even though one or two of the factories were on class A highways.

Actually, in the sample periods, 83 percent of the trips utilized class B roads, at least in part. However, in traveling to and from the areas of collection, the trucks used class A roads whenever possible. Thus, 67 percent of the total mileage traveled was on class A roads, even though only 17 percent of the trips used those roads exclusively.

At this mentioned hearing, the comptroller and the transportation superintendent of this whey-drying company described the situation it would face if the 1945 class B weight limits were enforced rigorously. Most of the vehicles operated by the company, they said, are 3-axle semitrailer tank trucks, designed to carry 27,000-pound payloads. With this load their gross vehicle weights average about 45,000 pounds. Gross weight, however, could be distributed among the axles so that legal capacity operation was possible on class A highways under the 1945 law. However, with capacity payloads the drive and trailer axles carried loads far exceeding the class B limit of 12,000 pounds. To comply with the class B limit, such a truck could carry a payload no larger than 13,000 pounds, which is slightly less than half of capacity.

28/ Report of public hearing on the transportation problems of the Wisconsin dairy industry. Op. cit.

29/ The highway classification was that of March 1950.

30/ Complete data for the company were obtained for 1 day each month (the Wednesday nearest the 15th of the month) for the 12-month period April 1949 to March 1950 inclusive. The statistics are aggregates for the 12 sample days.

Rather than operate its present equipment at only half capacity, the company reported that it would replace its trucks with new ones designed specifically for 12,000-pound axle loads. The new trucks would be single-unit vehicles rather than the semitrailer combinations now used. They would be of lighter construction than the present equipment, and could carry maximum payloads of only 9,000 pounds.

Table 5 shows operating data for the trucks used by this company in 1949, compared with operating data that could be expected in connection with efficient use of the new-type truck. The table indicates that for this whey-drying company, a rigorous enforcement of the 1945 class B law would result in an increase of more than $900,000 a year in costs of transportation. The significance of this increase in cost can be gauged when we consider that total payments by whey-drying companies for all the whey they processed amounted to some $850,000 in 1949. 31/

Table 5. - Cost of hauling whey in 1949 and probable cost using new type truck

Item	Unit	1949	New type truck
Type of vehicle		3-axle semitrailer	Single unit
Axle load	Pound	19,000	12,000
Payload	Do.	27,000	9,000
Operating cost per mile	Cent	27.85	1/ 22.00
Required travel	Mile	3,140,000	2/ 8,163,000
Total annual operating cost	Dollar	874,000	3/ 1,791,000

1/ Expected cost per mile was synthesized from the principal cost components: Wages, gas and oil, tires, depreciation, insurance, licenses, and repairs.
2/ Traffic department calculated the total mileage of travel necessary to collect the 1949 volume of whey under efficient utilization of vehicles with 9,000-pound payloads.
3/ Product of number of miles and the cost per mile.

Records of "X" Whey Drying Company.

An alternative for the cheese factories would be to return the whey to farmers for use as livestock feed. 32/ Under this alternative, cheese factories that now sell to drying plants would lose their $850,000 in payments.

31/ In 1946, more than half of the whey produced in the State was utilized in this fashion, mostly as hog feed. See Production and Distribution of Whey in Wisconsin, in Economic Information for Wisconsin Farmers. v. 19, nos. 9-10. Sept.-Oct. 1948.

32/ Highway Research Board. Bul. No. 26, p. 89. Op. cit.

Because the law forbids the discharge of whey into streams or roadside ditches, this method of disposal is no real alternative for the cheese factories. At present some of them, unable to sell to a central drying plant, haul the product to isolated sites and dump it into pits where it is absorbed by the soil. Other cheese factories have the whey treated in municipal sewage plants. These methods of disposal involve extra costs.

Another method of disposal might be to dry the whey at the cheese factories, although the difficulty here is that these factories are typically quite small. Further, the cost of drying equipment would exceed the total investment in many cheese factories, and even the largest plants try to avoid the processing of whey because of the relatively low volume.

Legislative changes in 1950 and 1951

On June 5, 1950, some of the facts and estimates relating to the effects of class B regulations on the cost of marketing fluid dairy products were presented in a progress report to the Highway Advisory Committee of the Wisconsin Legislative Council. About the same time, administrative officials withdrew 2,741 miles of State highways from the B classification and placed them in class A, subject to the higher class A load limits. This action left only 287 miles of State highways in the B class, but the 2,741 miles added to class A were to revert to the B class each year from March 1 through May 31. Previously the B system had been so classified on a year-round basis.

In 1951 the State legislature abolished the classification of State trunk highways, bringing all of them up to class A load limits. However, State administrative officials still are authorized to post highways when conditions warrant such action. This authority undoubtedly will be exercised, especially during the spring break-up.

Comparison of Wisconsin's 1945 Class A Load Limits with Those of Nearby States

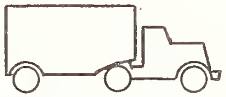
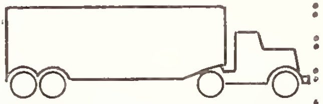
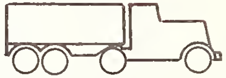
Table 3 showed that, for Class A highways, Wisconsin's 1945 law provided a limit of 19,000 pounds on the load carried on an individual axle, and limited the load on combinations of axles by a formula. This formula allowed a maximum of 30,000 pounds on tandem axles 4 feet apart.

With regard to these two types of limitations, most States have accepted the recommendations of AASHO, that is, 18,000 pounds on an individual axle and 32,000 pounds on tandem axles.

Unless specific vehicles with definite axle spacings are considered, it is difficult to compare the Wisconsin law with those of other States applying to gross vehicle weights and interior combinations of axles other than tandem axles.

Table 6 compares the practical weight limitations that would apply to typical vehicles on class A Wisconsin highways with those of neighboring States. The axle spacings of the vehicles considered in this table were taken from data collected in Wisconsin loadometer studies.

Table 6.- Limitations on weight of motortrucks, by types, Wisconsin and neighboring States, 1950

State	Maximum weight								
	Individual axle	Tandem axle	Axle combinations	Semitrailer combination vehicles					
				3 - axle 		4 - axle 		Dump truck, 4 - axle 	
				On rear: two axles	Practical gross vehicle 1/	On rear: three axles	Practical gross vehicle 1/	On rear: three axles	Practical gross vehicle 1/
	Pounds	Pounds		Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
Wisconsin 2/	19,000	30,000	Minimum of either formula or axle sums	38,000	47,000	49,000	58,000	38,000	47,000
Illinois	18,000	32,000	Sum of axles	36,000	45,000	50,000	59,000	50,000	59,000
Indiana	18,000	32,000	Sum of axles	36,000	45,000	51,000	60,000	33,800	42,800
Iowa	18,000	32,000	Minimum of either formula or axle sums	36,000	45,000	50,000	59,000	36,470	45,470
Michigan	18,000	32,000	Sum of axles	36,000	45,000	50,000	59,000	50,000	59,000
Minnesota	18,000	32,000	Minimum of either formula or axle sums	35,750	44,750	50,000	59,000	50,000	59,000

1/ Assuming a 9,000-pound load on the steering axle.
2/ Class A Highways, 1945 law.

Adapted from chart No. 8, p. 51 of Wisconsin Legislative Council 1950 Report, Vol. V, Sec. I., Part I. (Advisory Committee on Highways.)

The statutory limits that apply both to the typical 3-axle combination vehicle, and to the 4-axle combination having what can be termed a "full" wheel base do not differ widely. This uniformity tends to disappear, however, for a 4-axle vehicle with a shorter wheel base. An extreme case may be illustrated by the limits applying to a typical 4-axle semitrailer dump truck, as shown in table 6. In States that limit by formula the combined load on groups of axles, the maximum weights for short trucks are a good deal lower than in States which establish this limit by summing the permissible individual axle loads.

In considering uniform restrictions on weight, it must be remembered that effective weight restrictions are the statutory limits plus enforcement tolerances. In 1950 the Highway Research Board conducted a survey of the various States to determine tolerance policies. Their findings were summarized as follows:

"Enforcement agencies in six states stated that no tolerance was allowed, and seven advised that for evident reasons no stated tolerance was published. Some few advised that judgment was used, and allowance is made by some states for accumulations of mud and ice. Thirty-two of the states, some by statutory authority and some by their own delegated authority allow stipulated tolerances. These tolerances range from 0.5 to 10 percent with limitations on maximum allowable load." 33/

As noted, tolerances granted in connection with the 1945 Wisconsin law were as follows: 1,000 pounds applicable to the limitation of 19,000 pounds on an individual axle; and 2,000 pounds applicable to the bridge-formula limitation on the weight carried by combinations of axles, provided that the axle spacing under consideration was 12 feet or less. If the axle spacing was greater than 12 feet, the bridge-formula tolerance was 3,000 pounds.

For the other States listed in table 6, the Highway Research Board reported the following policies regarding enforcement tolerances. 34/ In Illinois, enforcement officials grant a tolerance of 300 pounds per axle. In Indiana, a tolerance of 1,000 pounds is granted by law, and this amount applies both to the weight on an individual axle and to the gross vehicle weight. (That is, any one axle may carry up to 1,000 pounds above the statutory 18,000-pound limit, but the sum of all axle loads may not exceed the statutory gross vehicle weight limit by more than 1,000 pounds). Officials in Iowa grant a 3-percent tolerance on the statutory axle-load limitation, and a 10-percent tolerance on the gross weight of vehicles. Michigan officials allow a 1-percent tolerance, whereas Minnesota allows 5 percent. 35/ From this brief examination it is obvious that the tolerance policies of the various States vary widely, and in addition, the application of these policies may not always be consistent.

33/ Highway Research Board Bulletin No. 26, "The Truck Weight Problem in Highway Transportation", page 89. Quoted in Wisconsin Legislative Council 1950 Report, Vol. V, Sec. I, Part I, page 42.

34/ See Bulletin No. 26, op. cit., page 99.

35/ The tolerance listed for some of these States includes the entire grant, whereas the amount listed for other States may include only the tolerance granted because of possible error resulting from the use of portable loadometer scales.

Through the years, considerable effort has been directed toward obtaining uniformity among States in highway weight limits. It would seem, however, that variety in policies of tolerance might offset, at least in part, the desirable effects of uniform statutory regulations. It is probable that substantial uniformity of policies of tolerance among the States cannot be achieved as long as those policies are formed at the discretion of enforcement officials. But there are grave objections to specifying the tolerance in the weight law. It is argued that if a tolerance is definitely specified, truckers will load close to the tolerance limit, and thus the statutory maximum will be exceeded consistently. Then too, the question of tolerances on tolerances might be encountered. That is, for administrative convenience, an unofficial tolerance may be used in the enforcement of the legal tolerance. If this occurs, a statutory maximum less than the tolerance limit is virtually meaningless. Yet it is generally agreed that some sort of tolerance is desirable for the purpose of effective, convenient, and economical enforcement

In transmitting their 1950 report, the Advisory Committee on Highways of the Wisconsin Legislative Council recommended that the tolerances be specified in the law, and that no arrest be made if the weights were less than the tolerance limits. However, if a load were above the tolerance limit, not only would an arrest be made, but in addition the tolerance would be forfeited in connection with the fines to be imposed.

A part of the fine was to be based on the following graduated scale of penalties:

Overweight	Penalty per pound on excess weight
Pounds	Cents
Less than 2,000	2
2,000 - 2,999	4
3,000 - 3,999	6
4,000 - 4,999	8
5,000 or more	10

The amount of overweight was to be calculated from the statutory limit, rather than from the tolerance limit.

This recommendation, for Wisconsin, was based on an adaptation of the 1949 Indiana law, which had been endorsed by the Indiana Motor Carriers Association, the Indiana State Police, and the maintenance division of the Indiana Highway Commission.

Under an arrangement such as that recommended for Wisconsin, the statutory maximum would retain some meaning, and tolerance would be likely to be viewed in its proper function — as an aid to effective enforcement, and as a defense for the trucker against faulty weighing devices, accumulations of mud and ice, shifting of the payload, and the like.

As finally enacted, the 1951 law provided for a flat fine if the load was less than 1,000 pounds above the tolerance limit. For greater loads, the graduated scale of penalties was to apply to the entire overweight calculated from the statutory limit.

Effect of the 1945 Class A Load Limits on the Marketing of Wisconsin Fluid Dairy Products, and Changes in 1951 Law

At the time this study was begun in 1950, the following sequence of events had affected the dairy industry: During World War II, previous trends in the industry's evolution were accelerated, and much consolidation of plants had occurred. Interplant hauling increased, and out-of-State shipments of milk were large. At that time the industry's truck-transportation system was able to expand sufficiently to support the war-time marketing pattern, even though transportation equipment was difficult to obtain. This adjustment was encouraged by the lack of enforcement of State highway weight laws during the war.

Wartime equipment continued to be protected by nonenforcement of the 1945 law and by the emergency legislation of 1949. But because much of it continued to be operated in 1950, concern was expressed regarding the effect on the dairy industry of vigorous enforcement of the 1945 law when the 1949 emergency amendment expired on July 1, 1951.

Vigorous enforcement of the 1945 class A law would impinge upon the marketing of the State's fluid dairy products principally through tank truck transportation of these products, both among plants in Wisconsin and from Wisconsin plants to those of other States. It is estimated that in 1949 some 400 tank trucks were engaged in this activity.

During 1950 an attempt was made to find out how many tank trucks carrying capacity loads of fluid dairy products would be in violation of the 1945 class A statutory limits. Contract haulers and companies doing their own trucking were requested to measure the axle distances on their tank trucks. They were asked also to weigh each axle when the truck was empty, and when it was carrying a capacity payload. Data were obtained on 237 tank trucks, including 15 two-axle single-unit vehicles, 114 three-axle semitrailer tankers, and 108 four-axle semitrailer units.

Load Limit on a Single Axle

In no case did the load on the steering axle of any vehicle even approach the 19,000-pound limitation, so these axles are excluded from the following tabulation. Because we are concerned here with the load limitation on individual axles, tandem axles also are excluded. Thus, the following tabulation (table 7) includes the drive axle of the single-unit tankers, the drive and trailer axles of the 3-axle combination tankers, and the drive axle of the 4-axle combinations.

Table 7. - Number and percentage distribution of trucks, by axle loads when loaded to capacity, May 1950

Axle load 1/	Trucks	
	Actual	Percentage distribution
Pounds	Number	Percent
19,000 or less	191	55
19,001 - 19,500	43	13
19,501 - 20,000	27	8
Over 20,000	84	24
Total	345	100

1/ Average axle load 18,957 pounds.

Thus, we see that when these tank trucks carried capacity payloads, 45 percent of the single axles had loads that exceeded Wisconsin's 1945 statutory maximum of 19,000 pounds, and 24 percent had loads that exceeded the tolerance limit of 20,000 pounds.

Wisconsin's 1949 special legislation for milk tankers did not change the 1945 statutory limit of 19,000 pounds on single axles. But the weights listed in table 7 are not necessarily those that were carried on the highways. Most of the trucks with axle loads listed above 20,000 pounds in table 7 were partially loaded when operating on the highways, so that on the road their axle loads were below the tolerance limit. Certain fluid dairy products such as whey, can be carried in partial loads because the sloshing of the product in the tank does not affect its quality. However, this is not true for all fluid dairy products, and most of the trucks having axle weights listed in the lighter categories were consistently operated with capacity payloads.

An examination of the statutory limitations on axle loads in States near Wisconsin, combined with consideration of the tolerance policies of those States, shows that trucks carrying axle loads in excess of 18,500 pounds are severely restricted in their interstate movements. As would be expected, many of the trucks represented in table 7 operated exclusively within the borders of Wisconsin, hauling fluid dairy products between plants within the State.

Some semitrailers that have heavy axle loads (when filled to capacity) are held on a standby basis for much of the year. They are pressed into service only from October to March, when the pressure on tank-truck facilities is greatest. During this period, supplies of milk from areas that usually serve southern markets are low, and interregional shipments of milk from Wisconsin are at their peak. These are long hauls, and a single trip requires a relatively long period of use of a truck. Therefore, to take care of interplant hauling within Wisconsin, the standby equipment is used.

To a considerable extent the trucking equipment represented in table 7 is specialized. Trucks used for interstate hauling have single-axle loads in the neighborhood of 18,000 pounds, even though under the 1945 and 1949 laws 20,000 pounds was the tolerance limit in Wisconsin.

Considering the tolerances granted by enforcement officials, the 1945 class A limitation on a single-axle load did not constitute a major worry for the Wisconsin dairy industry. Three-fourths of the single axles were within the load limit, including tolerance. Most of the remaining axles were on trucks that were already operated partially loaded. The owners of these vehicles were merely waiting to see what the 1951 legislature would do.

The 1951 Wisconsin legislature abandoned the statutory 19,000-pound single-axle load limitation that had been in effect since 1924. The statutory limit was reduced to 18,000 pounds, but the law specified that a tolerance of 1,500 pounds was to be granted. This change was not viewed as presenting a major problem to the dairy industry. Most of the heavy axles were drive or trailer axles (or both) of 3-axle semitrailer vehicles. Single trailer axles could often be replaced by tandem axles, and the "fifth wheel" [36] could be shifted so that weight could be taken off the drive axle and placed on the tandems.

Many vehicles were altered in this way. The 1951 limit on axle loads occasioned some loss and required some additional investment, but it was not contended that this would mean significantly increased trucking costs and rates for the industry as a whole, even though certain individual concerns would be hit.

The Bridge Formula

The class A bridge formula in the 1945 law definitely presented a problem to the Wisconsin dairy industry. Part of the emergency amendment in 1949 applied specifically to tank trucks carrying milk. The 1945 formula was 26,000 + [1,000 x L]. The formula provided to milk tankers by the special legislation in 1949 was 26,000 + [2,000 x L]. But the special legislation was due to expire on July 1, 1951, at which time a vigorous enforcement of the 1945 formula was planned.

For the 15 single-unit 2-axle tank trucks on which data were obtained in the survey, the 1945 bridge formula presented no problem. When fully loaded, these trucks had an average gross vehicle weight of approximately 23,000 pounds, and the bridge formula allowed 26,000 + [1,000 x L].

To examine the application of the formula to semitrailer vehicles, it is necessary to consider the axle spacings of those vehicles.

Table 8 shows the spacings between the drive and the trailer axles for the 114 three-axle semitrailer tankers for which data were obtained.

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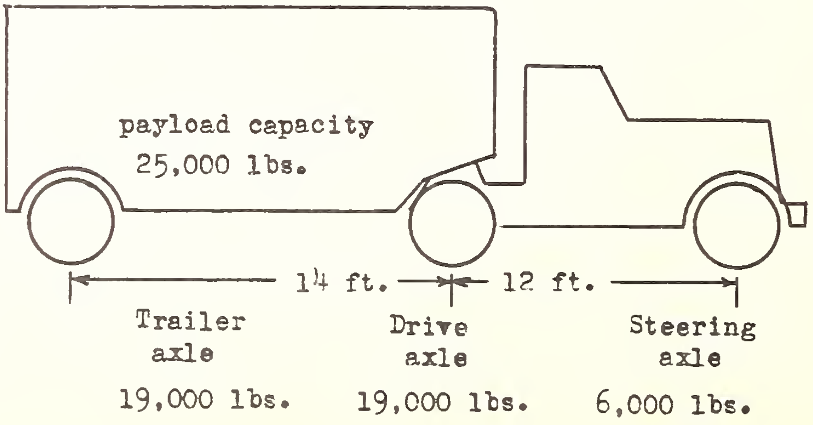
[36] The "fifth wheel" or kingpin, is a disk behind the cab of the tractor (power unit). The forward end of the semitrailer (load unit) rests on this disk. By shifting the "fifth wheel" closer to the cab, or closer to the rear axle of the tractor, axle loads can be changed.

Table 8. - Number of semitrailer tank trucks hauling dairy products, by axle spacings, Wisconsin, May 1950

Spacing between axles	Trucks with spacings between the drive and -	
	Trailer axles on a 3-axle vehicle	Front tandem axles on a 4-axle vehicle
Feet	Number	Number
10	2	1
11	4	-
12	9	3
13	13	2
14	37	10
15	32	6
16	13	35
17	-	20
18	-	3
19	-	1
20	1	3
21	-	7
22	3	8
23	-	9
Total	114	108

On almost all of these trucks the steering axle and the drive axle were 12 feet apart. Using the 14-foot modal class in table 8 as the spacing between the drive and the trailer axles, we can represent what might be termed typical axle spacings for these vehicles. From this it can easily be shown that the 1945 bridge formula presented no major problem for the 3-axle semitrailer tankers.



On the combination of the trailer and drive axles of the above vehicle, the 1945 bridge formula would allow 26,000 + [1,000 x 14] = 40,000 pounds. If the vehicle carried no more than the 1945 statutory limit of 19,000 pounds on either of these heavy axles, it would be unaffected by the formula for that combination. The formula would prevent the truck from carrying 19,000 pounds on each of these two axles only if the distance between them was less than 12 feet. Table 8 shows that on only 6, or 5 percent, of the trucks in question was the space between the drive and trailer axles less than 12 feet.

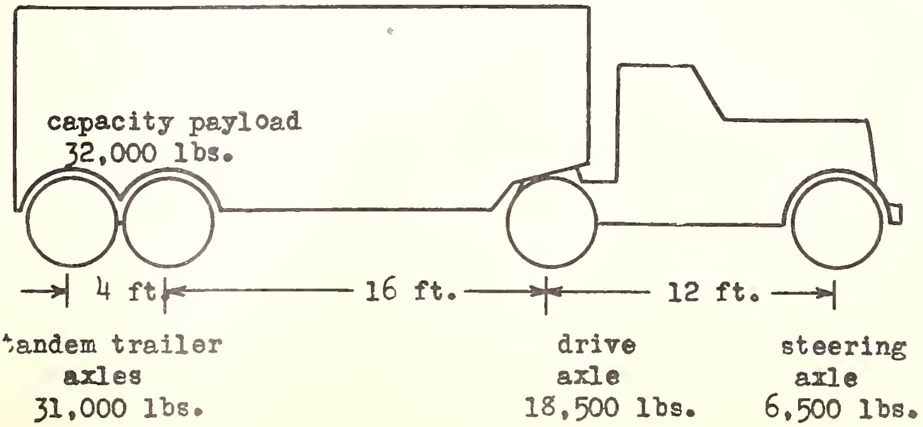
If the 1945 tolerances (both on the single-axle load and on the bridge formula) are considered, the situation remains unchanged. That is, under the bridge-formula maximum, including tolerance, 20,000 pounds could be carried on the drive and trailer axles if the distance between them was 12 or more feet.

On the combination of all three axles, the 1945 bridge formula would allow the typical vehicle (as illustrated) a total of 26,000 + [1,000 x 26] = 52,000 pounds. Because the total gross weight of the illustrated vehicle is only 19,000 + 19,000 + 6,000 = 44,000 pounds, it is easy to see that the bridge formula would not affect the permissible load on this combination of axles. Not even the shortest trucks represented in table 8 would have their gross vehicle weights restricted by the application of the formula to their over-all wheel base.

Thus we see that, among the samples of tank trucks, none of the 2-axle vehicles, and only 5 percent of the 3-axle units were affected by the 1945 class A bridge formula. However, the situation differed with regard to the 4-axle semitrailer tank trucks.

Table 8 also shows the spacings between the front tandem and drive axles for the 108 four-axle vehicles for which data were obtained.

In almost all the vehicles (table 8), 12 feet separated the steering and drive axles, and in almost all, 4 feet separated the tandem axles. Using the 16-foot modal class in table 8 as the spacing between the front tandem and the drive axle, we can represent what might be termed typical axle spacings for the 4-axle units.



The axle weights shown for the truck as illustrated are average weights, rounded to the nearest 500 pounds, for the 108 sample trucks of this type (when they carried capacity payloads).

This truck is seen to be in violation of the 1945 class A bridge formula 37/ for two combinations of axles: (1) the tandem trailer axles, and (2) the rear three axles (that is, the drive and the tandem axles). The bridge formula would allow 26,000 + [1,000 x 4] = 30,000 pounds on the tandem axles, whereas the typical truck illustrated above carries 31,000 pounds on these axles. The formula would allow 26,000 + [1,000 x 20] = 46,000 pounds on the rear three axles, whereas the typical truck carries 31,000 + 18,500 = 49,500 pounds on them.

The bridge formula tolerances 38/ granted by enforcement officials would cover the excess of the tandem axle load above the statutory maximum, but they would not cover the excess load on the combination of the rear three axles. The magnitude of the problem can be gauged when we consider that 53 percent of the trucks represented in table 8 had axle spacings equal to or shorter than the typical vehicle considered above. Obviously, the problem would be intensified for the shorter vehicles.

To carry the typical 49,500 pounds on the combination of the last three axles in strict compliance with the bridge formula (that is, excluding tolerances), an axle spacing of 20 or more feet would be required between the front tandem and drive axles. Table 8 shows that only 27 trucks (25 percent) would be in compliance.

In early 1950, a number of tank trailer units were "stretched" — that is, an extra 5 feet of frame was welded to the front end of the trailer, ahead of the actual tank. Commonly a false "nose" also was welded in front of the actual tank so that the vehicle would not look peculiar. Some of the longer axle spacings shown in table 8 were the result of such stretching operations, which were reported to cost more than $500 per trailer, and which in some instances were not very successful.

The longer axle spacings shown in table 8 include, in addition to the stretched units, a number of vehicles with trailers of new design. The tanks of these units are oval-shaped, shallow, and long. They are of the "trailerized" type (that is, the tank itself forms much of the trailer frame) and they have a payload capacity of 32,700 pounds of milk. This is slightly more than the typical capacity for a 4-axle tanker. These trailers cost approximately $10,000 each in 1950.

37/ It should be emphasized that at the time these data were collected (1950), trucks were operating under the 1949 special legislation. When carrying capacity loads, none of the trucks in the survey violated the special bridge formula applying to them under that emergency legislation. But, as stated previously, the 1949 special legislation was to expire July 1, 1951, after which vigorous enforcement of the 1945 law was planned.

38/ Report of hearing before Highway Advisory Committee of the Wisconsin Legislative Council, 1950. Part I, p. 65. Op cit.

The principal objection to trailers of this design relates to the shallow depth of the tank. It is only with difficulty that a man can maneuver himself inside it, hence cleaning difficulties have been reported.

These newly designed trailer combinations ordinarily carry 48,000 pounds on the last three axles: 30,500 pounds on the tandem trailer axles, and 17,500 pounds on the drive axle. Although this equipment would be within the tolerance limits in most States, it was designed specifically for hauling milk from Wisconsin sources to the Chicago market.

As presented in table 6, the Illinois law allows 18,000 pounds of load on an individual axle and 32,000 on tandem axles, so this vehicle would be legal in Illinois. The 1945 Wisconsin class A law allowed 19,000 pounds on an individual axle and 30,000 on tandem axles. Although the tandem axle load on the new vehicle exceeded the Wisconsin limit by 500 pounds, it was believed that this excess would be well within the enforcement tolerance to be granted after the 1949 emergency legislation expired. In other respects the new truck complied with the 1945 bridge formula. If this formula were vigorously enforced, the 32,700-pound payload of the vehicle in question would be the largest that could be carried from Wisconsin to Chicago. But a 4-axle semitrailer tank truck carrying a 34,000-pound payload can be operated legally in Illinois because of the more liberal limitation on tandem axle loads there.

Up to this point little has been said regarding the maximum practical gross vehicle weight allowed by the 1945 Wisconsin law. That law specified a maximum vehicle length of 45 feet. For a vehicle of this length, the maximum practical over-all wheel base is 40 feet. For this wheel base the bridge formula would allow a maximum gross weight of 26,000 + [1,000 x 40] = 66,000 pounds. This sets the maximum total gross weight for any type of vehicle in Wisconsin.

The largest 4-axle semitrailer tank truck encountered in the survey had a gross vehicle weight of 59,000 pounds (when carrying a capacity payload). So we see that the 66,000-pound limitation did not affect the 4-axle units. But if it were enforced it would prevent the operation of the standard type of 5-axle semitrailer tank truck and the so-called "double bottom" (a single-unit tank truck pulling a full tank trailer). These vehicles can be used in Illinois because that State permits a 72,000-pound gross vehicle weight. These vehicles can carry much larger payloads than the 4-axle vehicle used in Wisconsin.

On a given trip, truck operating costs per 100 pounds of payload tend to be lower for larger payloads. Because the relevant competitive price of milk in Chicago is the delivered price, a legal payload in Wisconsin lower than in Illinois places Wisconsin producers at a relative disadvantage in competition for the Chicago market.

Thus, the 1945 class A bridge formula, if rigidly enforced, not only would force the dairy industry to stretch or to re-equip most of its 4-axle tank trucks; it would also prevent the use of trucks as large as those that can operate legally in Illinois. 39/

39/ In 1949, about two-thirds of Wisconsin's out-of-State shipments of fluid whole milk moved to Chicago; of this milk, about 85 percent was carried in 4-axle semitrailer tank trucks.

Wisconsin Bridges and the Formula

As previously noted, the original reason for the bridge formula was related to the preservation of H-15 bridges, which generally predominate on the main roads of this country. Originally, gross vehicle weights were related to the over-all wheel base of the vehicle. Later, when the formula was revised and placed in tabular form, the weight-spacing relationships were recommended to apply to interior combinations of axles as well.

An H-15 bridge is designed to hold a single-unit 2-axle vehicle carrying 6,000 pounds on the front axle and 24,000 pounds on the rear axle, with a 14-foot space separating the axles. The number 15 in the symbol H-15 refers to the vehicle's gross weight of 15 tons (30,000 pounds).

An H-20 bridge is designed to carry a 3-axle single-unit vehicle with a gross weight of 40,000 pounds.

An H-20-S16 bridge is designed to carry a 4-axle semitrailer combination vehicle in which the tractor axles carry a sum of 40,000 pounds and the trailer axles carry 32,000 pounds, for a total gross vehicle weight of 72,000 pounds.

However, these design weights do not define the actual capacities of the bridges. A safety factor is always added, the typical structure in Wisconsin having a safety factor of "four." This means that Wisconsin bridges typically are built so as not to fail under a load of four times the weights used in the basic design. Actually, the "rated capacity" of a bridge is the relevant capacity in connection with axle spacings.

Table 9 shows the number and rated capacity of bridges on the State trunk-highway system at the present time, as estimated by the Bridge Department of the Wisconsin State Highway Commission. The tabulation shows that, on the State's trunk highways, the rated capacity of 70 percent of the bridges (H-20-S16 - 72,000 pounds) well exceeds the maximum practical gross vehicle weight allowed under the 1945 law (66,000 pounds). In principle, vehicles with weights approaching these rated capacities would encroach upon the safety factor of these bridges. Repeated applications of such weights would tend to shorten the lives of the bridges, but just how much effect there would be is not known. During and immediately following World War II, these bridges were subjected to vehicle loads exceeding those of the H-20-S16 design vehicle, apparently without serious damage.

The Advisory Committee on Highways of the Wisconsin Legislative Council summarized the situation as follows:

"It appears that the maximum weight limitations of vehicles as contained in the present law [the 1945 law] and the tolerances allowed in the enforcement of the law are of relative rather than absolute significance to the present inventory of bridges on the state trunk system. A shorter life can be expected from repeated applications of present legal loads but the present bridge system, as distinguished from individually classified bridges, is of no greater, if as great, a consideration in connection with the "emergency" legislation [the 1949 amendment] than the road surfaces over which the vehicles pass." 40/

40/ Wisconsin Legislative Council, 1950 Report. Op. cit., Part I, page 65.

Table 9. - Number and percentage distribution of "Trunk" bridges, by rated capacity, Wisconsin

Rated capacity 1/	Bridges 2/	
	Actual	Percentage distribution
	Number	Percent
H - 20 - S16	1,500	71
H - 20	500	24
H - 15 or less	115	5
Total	2,115	100

1/ All ratings are based on floor system and have drawn on the safety factor up to 80 percent.

2/ Tabulation applies only to bridges on the State trunk system. Current data are not available for bridges on county and local roads.

Wisconsin Legislative Council Report, 1950, Vol. V, Sec. I, Part I, p. 65.

What this says, in effect, is that the bridge formula is viewed to a large extent from the standpoint of the preservation of concrete pavement slabs. But the particular form that the formula takes and the scientific rationale for it, are given in terms of the preservation of H-15 bridges.

The original formula recommended by the AASHO in 1932 applied only to the over-all wheel base of vehicles. In this form it would not affect any of the vehicles reported in the survey undertaken in connection with this study. However, when this relationship between axle spacings and weights was applied to interior combinations of axles, as was the case with the 1945 Wisconsin formula and with the AASHO table recommended in 1946, the 4-axle vehicles were severely affected. In preserving pavement slabs, interior combinations of axles are the chief consideration because the over-all wheel base of 4-axle semitrailer units almost always exceeds the length of a pavement slab.

The rationale for using the bridge formula to protect pavement slabs usually runs something like the following: "It seems reasonable to suppose that more damage will be caused if three axles are on a slab simultaneously than if only two axles are on it. After all, a concrete slab acts as a bridge over the ground."

Granting the supposition that longer wheel bases tend to reduce the damage to pavement slabs, the question remains, should these regulations be framed in terms of H-15 bridges? It has yet to be shown that pavement slabs react to axle spacings in the same way as do bridges of the H-15 type. As an assumption, we might postulate that they would not react the same.

Under a bridge formula such as that contained in the 1945 Wisconsin law, a difference of only a few feet in wheel base can mean the difference between legal operation and the replacement of a fleet of trucks. Particularly is this

Table 10.- Weight of trucks, by axle spacings, under the Wisconsin Laws of 1945, 1949, and 1951

Spacing between axles	1945 bridge formula		1949 emergency law 1/	1951 law, including statutory tolerance
	Excluding tolerance	Including tolerance		
Feet	Pounds	Pounds	Pounds	Pounds
4	30,000	32,000	34,000	32,000
5	31,000	33,000	36,000	32,000
6	32,000	34,000	38,000	32,000
7	33,000	35,000	40,000	33,000
8	34,000	36,000	42,000	35,000
9	35,000	37,000	44,000	37,000
10	36,000	38,000	46,000	38,000
11	37,000	39,000	48,000	39,000
12	38,000	40,000	50,000	43,000
13	39,000	42,000	52,000	44,000
14	40,000	43,000	54,000	45,000
15	41,000	44,000	56,000	46,000
16	42,000	45,000	57,000	47,000
17	43,000	46,000	57,000	48,000
18	44,000	47,000	57,000	49,000
19	45,000	48,000	57,000	50,000
20	46,000	49,000	57,000	51,500
21	47,000	50,000	57,000	52,000
22	48,000	51,000	57,000	52,500
23	49,000	52,000	57,000	53,000
24	50,000	53,000	57,000	53,500
25	51,000	54,000	57,000	54,000
26	52,000	55,000	57,000	54,500
27	53,000	56,000	57,000	55,000
28	54,000	57,000	57,000	56,000
29	55,000	58,000	58,000	57,000
30	56,000	59,000	59,000	58,000
31	57,000	60,000	60,000	59,000
32	58,000	61,000	61,000	60,000
33	59,000	62,000	62,000	61,000
34	60,000	63,000	63,000	62,000
35	61,000	64,000	64,000	63,000
36	62,000	65,000	65,000	64,000
37	63,000	66,000	66,000	65,000
38	64,000	67,000	67,000	66,000
39	65,000	68,000	68,000	67,000
40	66,000	69,000	69,000	68,000

1/ Tank trucks carrying milk.

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the case if the trucks must carry capacity loads. For the tank-truck transportation of whole milk to bottle markets, this is virtually the situation. Actually, milk may be carried in partial loads, but the frothing and churning that takes place when this is done is considered undesirable by buyers, an important consideration in a competitive market.

Changes in 1951 Law

The 1951 Wisconsin legislature retained the 1945 bridge formula as the statutory device for setting maximum weights on combinations of axles. However, specific tolerances were provided in the law, and it specified that no arrest was to be made if the load was below the maximum, including tolerance. If the tolerance was exceeded by less than 1,000 pounds, a flat fine was to be imposed. If the tolerance was exceeded by more than 1,000 pounds, a flat fine was to be imposed plus a graduated fine on the overweight, which would be computed from the level set by the 1945 bridge formula.

Table 10 shows the permitted weights associated with the various axle spacings under the 1945, 1949, and 1951 laws. From this table it can be seen that the weights (including statutory tolerances) under the 1951 law generally were patterned after the 1945 weights including tolerances. However, for axle spacings between 12 and 24 feet inclusive, the 1945 maxima were raised by weights ranging from 500 to 3,000 pounds. With this upward revision, the typical 4-axle semitrailer milk tanker shown on page 43 would be safely within the tolerance limits. In fact, only about 15 percent of the 4-axle vehicles represented in table 8 would require stretching under the 1951 law.

In conclusion: When the bills, which later became law, were discussed at a public hearing before the Highway Advisory Committee of the Wisconsin Legislative Council, they were supported by representatives of the State highway commission, the railroads, the over-the-road dry-cargo truckers, and the fluid-milk haulers. It was said to be the first time that the four groups had supported the same legislation.

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